ENGINEERING NEWS
AND
AMERICAN RAILWAY JOURNAL.

Vol. XLVII. No. 10.

TABLE OF CONTENTS:

(24 *pages*; *no insct.*)

ENGINEERING NEWS OF THE WEEK..... 181
Progress Photographs of the New East River Bridge; New York city (illustrated)..... 182
Action on Wagon Roads (illustrated)..... 182
The Construction of the Aspen, Wyoming Tunnel on the Union Pacific Ry. (illustrated)..... 185
Concrete Roadbed Construction for Street Railways (illustrated)..... 188
Cost of Building Macadam Roads at Port Huron, Mich. (illustrated)..... 190
Reports on a New System of Water Supply for St. Louis..... 196
The New York Rapid Transit Railway. V. (illustrated)..... 199
Some Factors Affecting the Power of Locomotives (illustrated)..... 201
EDITORIAL NOTES..... 192
Legal Complications in Connection with the Panama Route for an Isthmian Canal—Is the Curvature on the Nicaragua Route an Important Obstacle to its Adoption?—A Franchise for the Entrance of the Pennsylvania R. R. to New York City—The Compulsory Use of the Metric System—"The Southern Review of Commerce" Again—An Example of Difficult Tunnel Lining.
EDITORIAL:
Some Reflections on the Luxemburg Bridge (illustrated)..... 193
LETTERS TO THE EDITOR.....194-195
The Rapid Extension of Concrete-Steel Construction—Non-Continuous Swing Spans—Still Further Discussion of the Upper Tallassee Dam—The Proper Crown for Macadamized Streets (illustrated)—Examples of High Earth Dams—Concerning Railway Location—Notes and Queries.

FIVE BIDS FOR THE PITTSBURG WATER PURIFICATION plant, described in our issue of Feb. 13, were received on Feb. 24, but the prices offered have not been officially announced, owing to a temporary injunction against the award of the contract. The suit was brought in the U. S. Court by a non-resident taxpayer, who claimed that the present contract did not cover all the works required, that estimates of the full cost of the plant had not been made, and that the contract would be illegal because the completed works would exceed the $2,500,000 bonds voted to pay for them. It is reported that the T. A. Gillespie Co., of New York, is the lowest bidder, and that its bid of $1,291,000 is an indication that the whole works can be built for $2,500,000.

THE OLD SEWAGE PURIFICATION PLANT at Madison, Wis., has been declared forfeited to the city by the contractor, the American Sanitary Engineering Co., of Detroit, Mich.; and the Fidelity & Guaranty Co., of Baltimore, has been held liable for the full $25,000 bond given by it, together with $1,045 interest. The decision was rendered in a jury trial, and an appeal may be taken, but the judge charged the jury that the contractors had failed to comply with his guarantees as to purity of effluent and cost of operation, while the city had kept its covenants in every particular. The plant in question was described at length in our issue of Dec. 28, 1899, at which time we pointed out various peculiar features of the contract. In our issue of Jan. 18, 1900, we commented editorially on the abandonment of the plant by the contractor, and on Oct. 11, 1900, we published an abstract of a detailed report by Prof. F. E. Turneaure, Assoc. Am. Soc. C. E., City Engineer of Madison, showing how the plant had failed to comply with the contract. Since the latter date the city has installed septic tanks and contact filter beds (some of the latter are still under construction). The new works were built under the direction of Profesor Turneaure, who described them in a paper read before the American Society of Municipal Improvements, last fall, and abstracted in our issue of Oct. 17, 1901.

THE COLUMBUS WATER METER CONTRACT, noted in our issue of Feb. 20, as divided between four companies, has been declined by the Thomson, Neptune and Pittsburg companies, unless the price, on the divided contract, is made $8 for ⅝-in., $12 for ¾-in., and $16 for 1 in., including connections. This, it is said, is an increase of $2 for each size of meter. The Hersey Mfg. Co. did not join the other companies in the action stated. From the Columbus papers one would infer that the reported contracts were informal, and that the city proposed to order the meters in small lots, to fill the orders received from private consumers. Mr. Fred. J. Immel is Director of Public Improvements.

DAMAGES FOR $12,000 FOR INADEQUATE FIRE PROtection must be paid by the Graves County Water & Light Co., of Mayfield, Ky. This decision is on affirmation by the Kentucky Court of Appeals. The building in question was burned in June, 1901, at a time when there was but little water in the water tower of the company. The court holds that a property owner may bring action against a water company for damages caused by the failure of the company to maintain a water supply in accordance with the terms of its contract with the city.

THE GRAND RAPIDS WATER CONTRACT SCANDAL has resulted, thus far, in the conviction, by jury trial, of two persons. A young Eastern capitalist has just been found guilty of supplying $75,000 to bribe the city council to award a $4,000,000 contract for a supply of water from Lake Michigan. The former conviction involved a man who was city attorney at the time of the deal, and who undertook to secure the award of the contract. There are one or more other persons yet to be tried, and one man turned State's evidence.

THE PUBLIC WORKS OF CHICAGO and all the departments of the city government will be run on a poverty-stricken basis this year, owing to the failure of the tax assessments to provide sufficient funds. Very little engineering work will be done, and the appropriation bill will not set aside enough money for repairing the existing bridges or building new ones, and barely enough for maintaining the electric lighting plant, without any extensions. Street cleaning will be practically abolished, and the health, fire and police departments will be allowed much less money than last year. Public improvements will have to be postponed until the city is in better financial condition, and the ordinary work of street paving and repairs, water main extensions, etc., will be reduced to a minimum in view of the limited appropriations. The mayor blames the board of review for this state of affairs, on the ground that it has not raised the assessments; the board, on the other hand, blames the mayor on the ground that he does not enforce the collection of taxes from street railways and other corporations, but makes real and personal property bear the whole burden of taxation.

THE MOST SERIOUS RAILWAY ACCIDENT of the week occurred on the Columbus branch of the Southern Ry. on Feb. 28. A southbound passenger train was passing over a trestle near Zetella, Ga., when three bents of the structure failed, dropping the whole train, with the exception of one car, into the creek below. Four men, all of them belonging to the train crew, were killed. The train ran over the trestle cautiously at low speed, on account of the recent heavy rains, but the structure had been weakened by the high water and failed.——Another wreck due to floods occurred on the Harlem division of the New York Central & Hudson River R. R. on Mar. 1. While rounding a sharp curve just south of Philmont, N. Y., a freight train broke through a washed-out culvert. Three men of the train crew were killed.——Three men were killed on Feb. 24 in a butting collision between two freight trains on the Chicago & Northwestern Ry., near Summit Lake, Wis. The cause of the wreck is not reported.

A HIGHWAY BRIDGE AT COLUMBUS, GA., was washed away on Feb. 27, and with it went out a section of the supply main of the Columbus Water-Works Co. The failure was due to a heavy rainfall that did much damage throughout the South. The bridge was in the line of 14th St. It was of the Town's lattice-girder type, covered in, and was built in 1867. The failure was due to a collapse of one of the piers, which occurred several hours before the time of maximum flood. The city had recently voted $40,000 bonds for replacing this bridge with a modern steel structure, and plans for the new bridge are now about ready. If it were not for the inconvenience caused by the interruption of traffic and the effect on the public water supply, the washing out of the old bridge would have been a good thing, as it saves the expense and trouble of removing it. The water supply of the city of Columbus is from impounding reservoirs, located about five miles from the city in the State of Alabama. The 12-in. supply main is brought into the city across the 14th St. bridge, using two 9-in. wrought-iron pipes, which were suspended, one on either side of the bridge. When the bridge failed these pipes were, of course, carried out, and the city was cut off from the reservoirs. Fortunately, the city can be supplied with water direct from the river by means of a small pumping plant which was put in by the water company about a year ago for the purpose of pumping to a high-service portion of the system in an elevated portion of the city. This pumping plant is located in one of the water-power plants on the river, and has a connection so as to take water from the river; ordinarily they drew from the main supply and pumped to the higher level. The river water makes the city comparatively safe against fire, but it is a most objectionable water for domestic use, as the Chattahoochee River is a very muddy stream. For the information given above we are indebted to Mr. Robt. L. Johnson, Superintendent of Public Works of Columbus, Ga.

THE PARK AVE. TUNNEL DISASTER of Jan. 8 has resulted in the indictment by the Grand Jury of John M. Wisker, the engine-driver who ran past signals into the rear of the New Haven train. The charge in the indictment is manslaughter. No indictments were found against the railway company or its officers.

THE FALL OF A STEEL ROOF IN CHICAGO killed two men and injured several others, on Feb. 28. The roof was that of a building at the plant of the South Chicago Furnace Co.; it was of galvanized iron on steel trusses, and according to a news report the fall was due to weakening of the trusses.

A BUILDING COLLAPSED IN CLEVELAND, O., on March 1, resulting in injuries to a dozen people and probably also the loss of several lives. The fourth floor of a building occupied by the Cleveland Baking Co. gave way and fell through the floors below to the ground. It is not yet known how many were caught in the collapse, but a number of people are missing, and, it is thought, are buried under the ruins. Nothing is known as to the cause of the accident.

MUCH LOSS OF LIFE FROM SNOWSLIDES during the past week is reported from Colorado. Immense quantities of snow lie all over the state; traffic, especially in the mountain districts, is almost entirely suspended and wires are down at many points. On the morning of Feb. 28 a series of slides occurred on Smuggler Mountain, near Telluride, Colo., of which the first overwhelmed the bunk-house and the boarding-house of the men of the Liberty Bell mine, carrying both buildings, with possibly sixty men, far down the mountain side; the second slide, several hours later, followed in the track of the first, and buried a score or more of the rescuing party. The list of the killed will not be known even approximately for some time. On March 2, a snowslide at the Sunny Side mine, only a short distance from the Smuggler group, carried away all the buildings of the mine, and with them about twenty miners. Smaller slides are reported from several other points, each claiming one or more victims.

A WATER-TANK FAILURE AT VERMILLION, S. Dak., is reported as having occurred Feb. 21, or a day or two earlier. The tank had a capacity of about 50,000 gallons, and was 100 ft. above the ground. From the fact that the failure is attributed to "rusty hoops," it may be assumed that the tank was of wood. The tank was owned by the Vermillion Water-Works Co., which put its works in operation in 1890.

THE OLD BROOKLYN BRIDGE, under the new Commissioner of Bridges and the Chief Engineer of Bridges, is being regularly inspected, and reports of condition are made monthly to Mr. Buck. Daily inspections are made of important points, the work being divided between Assistant Engineer McLean and three assistants. The new suspenders at the center of the main span, which replace those that broke last summer, are much stronger and have larger trunnions than the old ones; the bearings are oiled once a month.

THE MARCONI WIRELESS TELEGRAPH was worked last week from the steamship "Philadelphia," receiving actual messages from the station at Cornwall, England, up to a distance of 1,551 miles; the signal letter "S" was received up to 2,099 miles. Full messages were received at 250.5, 464.5, 1,032.3, 1,163.5 and 1,551.5 miles from the station at Poldhu, Cornwall and the signal "S" at 2,099 miles, according to the official report signed by Capt. A. R. Mills, of the "Philadelphia." The messages received were as plain as those sent 30 miles. Mr. Marconi says that within three months he expects to have stations on both sides of the Atlantic regularly equipped for doing business in sending and receiving messages. On this side there would be two stations, one at Cape Breton and another at Cape Cod.

MILITARY AMBULANCE WAGONS are wanted by the English Secretary of State for War, and he offers prizes of $2,500 and $1,250 for the best and most suitable design for these wagons. The latest date for entering the competition, however, is March 15, 1902, and conditions can only be had by writing to the Director-General of Ordnance, War Office, Pall Mall, London, England.

BY-PRODUCT COKE OVENS are being built at Sparrows Point, Md., by the Maryland Steel Co., and a contract has been made for the sale of the gas produced to the Consolidated Gas Co., of Baltimore.

PROGRESS ON THE SIMPLON TUNNEL for January, 1902, is reported as follows: The advance of the two main headings aggregated 690 ft., of which 683 ft. was on the north side, 7 ft. on the south side. This brings the total advance of both headings, to date, to the figure of 35,990 ft. The number of men employed averaged 8,231, about the same as in the previous month. The north heading was alternately in thinly stratified gneiss and crystalline slatey or schistose rock; an average daily advance of 22 ft. was reached with machine drilling. In the south heading only hand drilling could be used, the rock being the same disintegrated, calcareous micaschist is in the past months. The timber bracing became insufficient and steel strutting is now employed. The flow of water is about the same as during December.

PROGRESS PHOTOGRAPHS OF THE NEW EAST RIVER BRIDGE WORK, NEW YORK CITY.

We present herewith some recent photographs of portions of the suspension bridge now in process of construction between Delancey St., New York, and South Sixth St., Williamsburgh, Brooklyn, known as the New East River Bridge. These pictures will serve to illustrate the manner in which the work is being carried on at its present stage, and show to what extent the work has progressed.

The connecting spans of the bridge, as well as the main supporting towers (steel), on both the Brooklyn and New York shores were practically completed by April, 1901, and the work of placing the temporary footwalk or erection cables was then begun. The foot-walks were completed in June, 1901. The actual work of "spinning" the main cables was begun in the latter part of November, 1901. This is evidently the most important single portion of the work of constructing the bridge, in the first place because the strength of the completed structure is directly dependent upon the cables, in the second place because the total time necessary for building a suspension bridge hinges chiefly on the rate at which the cables can be strung. Until the cables are laid up and in place, no work can be done on the erection of the trusses, roadway, etc., of the suspended span. The methods of "spinning" the cables is therefore of much interest.

There are to be four cables, each composed of 7,696 wires each 3-16-in. in diameter. The cables are laid up in separate strands, each cable having 37 strands of 208 wires each. Such a strand is laid up as one continuous wire, looped successively around shoes through which the end pins are to pass (the turns of the wire are all parallel), and passing over a line of sheaves at the tops of the towers. When the strand is completed it is adjusted and dropped from the sheaves into the saddles. The tension on a strand is about 25 tons. It is adjusted by means of large ratchet jacks at its ends and connected in its final position to the anchorage eye-bars by 7-in. pins.

The photograph reproduced in Fig. 1 was taken at the top of one of the towers; two finished strands of a cable will be seen, one of which is being lowered into its position in the saddle, where a number of previously completed strands are already in place. Fig. 2 shows the anchorage end of the cables; the large ratchet-jacket is being used to adjust one of the finished strands while another strand is still held on the shoe over which it was laid up. At the right of the picture will be seen the reels of wire used in the work; at the left is the traveling sheave, employed to carry the loops of wire across the span.

The traveling sheave is shown more clearly in Fig. 3, which shows the working platform at the anchorage, to the right and above in Fig. 2. An endless cable extends across the span at some distance above the main and footway cables. A large sheave is attached to this cable as shown, and travels with the cable, there being one sheave on each span of the cable. A bight of wire from the reel is thrown over the sheave at each anchorage, and thus as the sheave passes from one side to the other, two wires are laid in the strand at the same time. As can be best seen in Fig. 1, two strands of each cable are in process of laying at once. A more comprehensive view of the work at the anchorages is given in Fig. 4, which shows the ends of the two center cables at the Brooklyn anchorage. The traveling wheel is here seen at the right, just starting on a trip across the span. The end shoes over which the separate strands are laid up can be seen in the middle. The trusses above are portions of the steelwork of the connecting spans.

FIG. 1. VIEW AT TOP OF TOWER OF NEW EAST RIVER BRIDGE, NEW YORK, SHOWING TWO STRANDS COMPLETED AND READY TO BE DROPPED INTO CABLE-SADDLES.

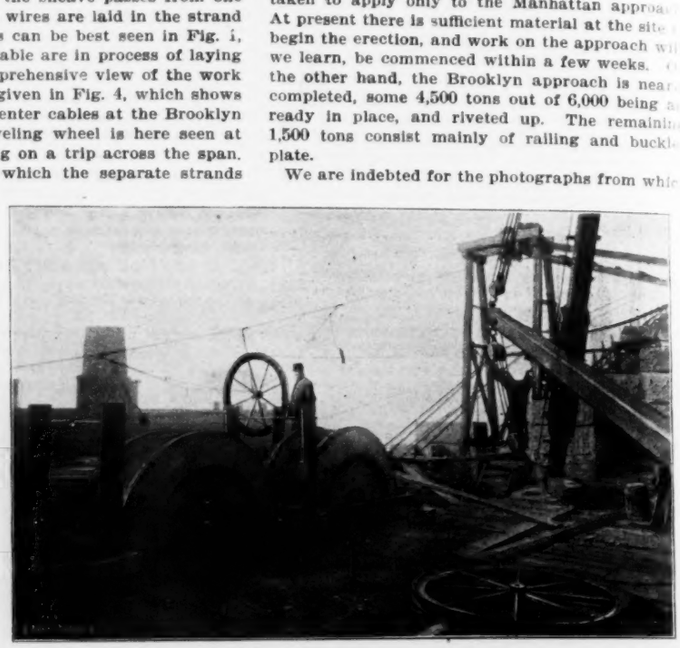


FIG. 3. VIEW ON WORKING PLATFORM AT ANCHORAGE, SHOWING CABLEWIRE REELS AND TRAVELING SHEAVE.

There are usually four wheels in operation, and except for the time required for adjustment of the strands they work continuously during the working day of ten hours, making about sixteen round trips per day. Up to the present, 40 strands have been completed, out of a total of 148 strands for the four cables.

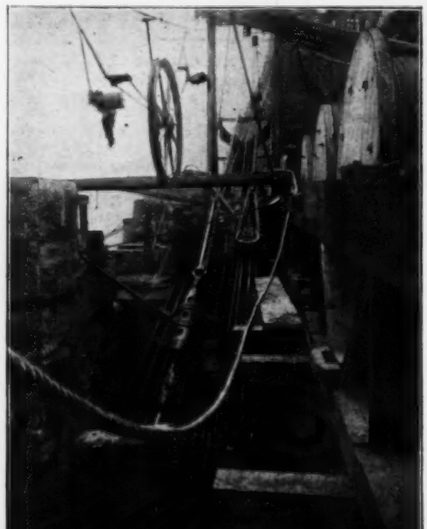


Fig. 2. View at Anchorage, Showing Tension Adjustment of Cable Strand.

As noted above, the connecting spans, which comprise those portions of the structure connecting anchorage and main tower at either end, were completed in April, 1901. In reference to the approach spans, running from anchorage to street level, a note in our issue of Jan. 30, 1902, stated that none of the material for them had yet been delivered on the ground. This statement was to be taken to apply only to the Manhattan approach. At present there is sufficient material at the site to begin the erection, and work on the approach will, we learn, be commenced within a few weeks. On the other hand, the Brooklyn approach is nearly completed, some 4,500 tons out of 6,000 being already in place, and riveted up. The remaining 1,500 tons consist mainly of railing and buckle plate.

We are indebted for the photographs from which our engravings are made to Mr. J. M. Evans, Chief Inspector of Erection, New East River Bridge.

TRACTION ON WAGON ROADS.

By Ira O. Baker, M. Am. Soc. C. E.*

Some experiments on the tractive power required to draw wagons on different roads and pavements were recently made by the writer, and it is thought that the results may possibly be of interest. The subject of traction is only briefly considered in any engineering literature with which the writer is acquainted; so before giving an account of his own experiments, he will discuss the general subject.

The resistance to traction of a vehicle on a road consists of three independent elements: axle friction, rolling resistance and grade resistance. Nothing need be said here concerning grade resistance, since engineers understand perfectly well that it is equal to 20 lbs. per ton for each 1% of grade.

AXLE FRICTION.—The resistance of the hub to turning on the axle is the same as that of a journal revolving in its bearing, and has nothing to do with the condition of the road surface. The coefficient of journal friction varies with the material of the journal and its bearing, and with the lubricant. It is nearly independent of the velocity, and according to observations made by the author, seems to vary about inversely as the square root of the pressure. For light carriages when loaded, the coefficient is about 0.020 of the weight on the axle; for the heavier carriages when loaded, about 0.015; and for the ordinary American thimble-skein wagon when loaded, the coefficient of friction is about 0.012. The above figures assume good lubrication. If there is a deficiency of lubricant, the axle friction is 2 to 6 times as much. The above figures agree reasonably well with results obtained for journal friction of machines. Apparently the value of this coefficient in Morin's experiments was 0.065. This difference is probably due to the better mechanical construction of modern American carriages and wagons.

The tractive power required to overcome the

*Professor of Civil Engineering, University of Illinois, Champaign, Ill.

axle friction for American carriages of the usual proportions is about 3 to 3¼ lbs. per ton of the weight on the axle; and for wagons with medium-sized wheels and axles, about 3½ to 4½ lbs. per ton.

ROLLING RESISTANCE.—The resistance of a wheel to rolling along on a road is due to the yielding or indentation of the road, which causes the wheel to be continually climbing an inclination. The resistance is measured by the horizontal force necessary at the axle to lift the wheel over the obstacle or to roll it up the inclined surface. The rolling resistance varies with (1) the diameter of the wheel, (2) the width of the tire, (3) the speed, (4) the presence or absence of springs on the vehicle, and (5) the nature of the road surface.

1. DIAMETER OF WHEEL.—The rolling resistance varies inversely as some function of the diameter of the wheel, since the larger the wheel the greater the force required to lift it over the obstruction or to roll it up the inclination due to the indentation of the surface. Table I., from an unpublished bulletin of the Missouri Agricultural Experiment Station, shows the results obtained by Mr. T. I. Mairs at this Experiment Station with different sized wheels. The three sizes of the wheel used were as follows: The 50-in. being 44-in. front wheels and 56-in. hind wheels; the 38-in. being 36-in. front and 40-in. hind wheels; and the 26-in. being 24-in. front and 28-in. hind wheels. The load was practically 1¾ tons in each case.* The tires were 6 ins. wide.

FIG. 4. GENERAL VIEW AT BROOKLYN ANCHORAGE, LOOKING TOWARD MAIN TOWERS.

TABLE I.—Effect of Size of Wheels on Traction.*

Description of road surface.	Mean diameter, of front and rear wheels, ins. 50	38	26
	Tractice force, lbs. per ton.		
Macadam:			
Slightly worn; clean; fair condition	57	61	70
Gravel road:			
Dry; sand 1-in. deep; loose stones...	84	90	110
Up-grade 2.2%; ½-in. wet sand, frozen below.	123	132	173
Earth road: Dry and hard.	69	75	79
½-in. sticky mud; frzn below; rough	101	119	139
Timothy and bluegrass sod:			
Dry, grass cut.	132	145	179
Wet and spongy	173	208	281
Cornfield: Flat culture; across rows; dry	178	201	265
Plowed ground:			
Not harrowed; dry; cloddy.	252	303	374
Average value of the tractive power	130	148	186

*From a bulletin, not yet published, of the Missouri Agricultural Experiment Station.

*In all the data herein, the ton is 2,000 lbs. In engineering literature on traction there is great confusion between "long" and "short" tons.

TABLE II.—Traction of Broad and Narrow Tires.*
(Figures give resistance to traction in lbs. per ton.)

Description of the surface.	Width of tire, 1½ ins.	Width of tire, 6 ins.	No. of trials.
Broken Stone Road: Hard, smooth, no dust, no loose stones, nearly level	121	98	2
Gravel Roads: Hard and smooth, few loose stones size of black walnuts	182	134	2
" " Hard, no ruts, the large quantity of sand prevented packing.	239	157	1
" " New, gravel not compact, dry	330	260	1
" " Wet, loose sand 1 to 2½ ins. deep	246	254	2
Earth Roads: Loam, dry, loose dust 2 to 3 ins. deep	90	106	2
" " " hard, no dust, no ruts, nearly level	149	109	3
" " " stiff mud, drying on top, spongy below	497	307	1
" " " mud 2½ ins. deep, very sticky, firm below	251	325	1
" " Clay, sloppy mud, 3 to 4 ins. deep, hard below	286	406	1
" " " dry on top but spongy below, narrow tires cut in 6 to 8 ins.	472	422	2
" " " dry on top but spongy below	618	464	5
" " " stiff deep mud	825	551	1
Mowing Land: Timothy sod, dry, firm, smooth; narrow tire cuts in 1 in.	317	229	1
" " " " moist; narrow tire cuts in 3½ ins.	421	305	1
" " " " soft and spongy, grass and stubble 3 ins. high; nrw tire in 6 ins.	569	327	1
Pasture Land: Blue grass sod, dry, firm, smooth.	218	156	2
" " " " soft; narrow tire cuts in 3 ins.	420	273	2
" " " " narrow tire cuts in 4 ins.	578	436	1
Stubble Land: Corn stubble, no weeds, nearly dry enough to plow	631	418	2
" " " " some weeds and stalks, dry enough to plow	423	362	1
" " " " in autumn dry and firm.	404	256	2
Plowed Land: Freshly plowed, but not harrowed, surface rough	510	283	1
" " " " harrowed; smooth and compact.	466	323	1

*Missouri Agricultural Experiment Station, Bulletin No. 39, July, 1897.

Morin concluded that the resistance varies inversely as the first power of the diameter of the wheel; Dupuit, that it varies inversely as the square root; and Clark claims that it varies inversely as the cube root.* According to some experiments made in England in 1874,† the traction varied more rapidly than the first power of the diameter of the wheel. The results in Table I. vary nearly inversely as the square root of the mean diameter—certainly more nearly than either the first power or the cube root. For obvious reasons, the experiments can not be very exact; and probably the traction varies differently for different surfaces. The exact determination of the law of variation is of no great importance.

2. WIDTH OF TIRE.—If the wheel cuts into the road surface, the traction is thereby increased; but with surfaces for which there is little or no indentation, the traction is practically independent of the width of the tire.

Table II. shows the results of an elaborate series of experiments by the Missouri Agricultural Experiment Station.* The load in each case was 1 ton. These results show that on poor macadam, poor gravel, and compressible earth roads, and on agricultural lands, the narrower tire gives less traction, except as follows: (1) when the earth road is sloppy, muddy or sticky on top, and firm underneath; (2) when the surface is covered with a very loose, deep dust, and is hard underneath; (3) when the mud is very deep, and so sticky that it adheres to the wheel; or (4) when the road has been rutted up with the narrow tire. The last conclusion was established by a large number of experiments not included in Table II.

Table III. gives data on the effect of width of tire upon the tractive force obtained by the Studebaker Bros. Mfg. Co., South Bend, Ind., in 1892, with an ordinary 3½-in. thimble-skein wagon. Notice that on a hard and incompressible road surface, namely, wood block pavement and gravel, the narrower tire draws the easier; while upon the soft or spongy surface the wider tire draws the easier. Morin† experimented with tires 2½, 4½ and 6½ ins. wide, and concluded that on a solid road or pavement the traction was independent of the width of the tire, and that on a compressible surface the traction decreased as the width of the tire increased, the proportions depending upon the nature of the surface.

3. EFFECT OF SPEED.—The rolling resistance increases with the velocity owing to the effect of the shocks or concussions produced by the irregularities of the road surface. The increase is less for vehicles having springs than those not, and is less for smooth road surfaces than for rough ones.

Table IV. is a summary of Morin's results, showing the effect of a variation of the speed, for vehicles provided with springs. In a rough

TABLE III.—Effect of Width of Tire upon Tractive Power.*
(Figures gives resistance to traction in lbs. per ton.)

Description of the road surface.	Diameter of front and rear wheels. 42 and 46 ins.				44 & 54 ins.		42 & 46 ins.		44 & 54 ins.	
	Width of tire, ins. 1½.	4.	1½.	4.	1½.	4.	1½.	3.	1¾.	3.
Sod	..	..	..	..	..	..	283	239	189	228
Roads:										
Earth: Hard	108	..	..	..	..	..	152	152	114	114
Muddy	243	268	304	236	254	..	..	..	265	228
Sand: Hard.	199	162	171	134	141	168	..	..	..	..
Deep	371	351	..	..	..	..	..	..	..	..
Gravel.†	..	..	98	117	83	80	..	..	66	76
W'd bl'k, r'nd	51	49	61	70	35	46	..	54	28	38

*Pamphlet by Studebaker Bros. Mfg. Co., South Bend, Ind. 1892.
†Good.

*Clarke's "Construction of Roads and Streets," p. 294; London, 1890.
†Clarke's "Manual of Rules, Tables and Data for Mechanical Engineers," p. 962. London, 1877.

TABLE IV.—Effect of Speed on Tractive Power.*
(Figures give resistance to traction in lbs. per ton.)

Description of the road surface.	Stage coach. Walk.	Trot.	Fast trot.	Carriage. Walk.	Trot.	Fast trot.
Broken Stone Road.						
Good condition, dry, compact	42	49	50	41	48	49
Very firm, large stones visible	59	75	81	58	73	81
Little moist, or little dirty..	49	75	88	48	74	88
Firm; little soft mud	77	92	100	76	91	99
Firm; ruts and much mud..	95	108	117	93	108	116
Port'ns worn out; thick mud.	112	127	134	110	126	132
Much worn; ruts 3 ins., mud	146	161	169	145	160	168
Very bad; ruts 4 ins., rough	164	180	..	162	202	..
Stone Block Pavement.						
Very smooth; narrow joints.	32	48	55	31	47	54
Fair condition; dry	35	52	61	34	51	67
Moist, covered with dirt.	35	49	56	44	60	67

*Morin's Experiments.

*Missouri Agricultural Experiment Station, Bulletin No. 39, 1897.
†"Experiences sur le Tirage des Voitures sur les Effets Destructeurs qu'elles Exercent sur les Routes; Executees en 1837 et 1838 par ordre du Ministre de la Guerre, et 1839 et 1841 par ordre du Ministre des Travaux Publics," A. Morin, Paris, 1843.

way the three speeds are 2½, 5, and 7½ ft. per second, or about 2, 4, and 6 miles per hour, respectively. It is frequently claimed that Morin's results show that the traction increases as the velocity above 2½ miles per hour. Table IV. certainly does not support this claim; and other experimenters report a greater increase of traction with an increase of speed than Morin.

The preceding data refer to the effect of speed upon the tractive power after the load is in motion. It requires from two to six or eight times as much force to start a load as to keep it in motion at two or three miles per hour. The extra force required to start a load is due in part to the fact that during the stop the wheel may settle into the road surface, and also in part to the fact that the axle friction at starting is greater than after motion has begun, and farther in part to the fact that energy is consumed in accelerating the load.

4. EFFECT OF SPRINGS.—Springs decrease the traction by decreasing the concussions due to irregularities of the road surface, and are therefore more effective at high speeds than at low ones, and on rough roads than on smooth ones. Apparently no experiments have been made upon the effect of springs; but a little data on this subject can be obtained by comparing the sixth column (that for the artillery wagon) of Table V. with the last column of the same table.

5. DIFFERENT ROAD SURFACES.—Immediately before and shortly after the introduction of railways, European engineers made many experiments on the force necessary to draw different vehicles over various surfaces. The experiments by Morin, made in 1837-41 for the French Government, were much the more elaborate, and appear to have been made with great care. Table V. is a summary of his results for the traction of different vehicles on various road surfaces.

TABLE VI.—Tractive Resistance of Level Pavements.

Ref. No.	Description of pavement.	Lbs. per ton.
1.	Asphalt: Chicago—Calumet Ave., bet. 43d and 44th Sts.; clean, smooth, no cracks, 52° F.	37
2.	Chicago—Calumet Ave., between 43d and 44th Sts.; clean, smooth, no cracks, 84° F.	70
3.	Chicago—Washington Boulevard, bet. Halsted and Green Sts.; clean, smooth, no cracks, 42° F.	34
4.	Brick: Champaign—University Ave., west of New St., 3x9 ins., brick on concrete, corners rounded, sand filler, not worn, clean.	17
5.	Champaign—Second South St.; as above except newer and covered with ½-in. of dust.	31
6.	Champaign—First South St.; as No. 4, except cement filler; just completed	22
7.	Chicago—Peoria St., between Washington and Randolph; 2¼x8-in. brick on concrete; pitch filler; new	24
8.	Chicago—Laurel St., stock yards, 3x8-in. brick on gravel and cinders; sand filler, corners not rounded	37
9.	Chicago—Exchange Ave., stock yards, 2¼x8-in. brick on sand and old macadam; tar filler; new.	25
10.	Granite Block: Chicago—Exchange Ave., stock yards; smoothly dressed 3x9-in. blocks on concrete, joints ¼-in., tar filler; not worn	29
11.	Chicago—Randolph St., between Desplaines and Halsted; smoothly dressed, on concrete, pitch filler; new	30
12.	Chicago—Halsted St., between Randolph and Washington; ordinary granite, laid in 1892	36
13.	Macadam: Chicago—Michigan Ave., between 42d and 43d Sts.; granite top; no dust; no mud	18
14.	Plank Road: Oak plank, 3 × 12-in., nearly new	32
15.	Exactly same as above after worn down ¼-in. in many places; clean.	38
16.	Substantially same as above; covered with ¼-in. fine, loose dirt.	40
17.	Steel Wheelway: 8-in. 11¼-lb. channel on 2x8-in. pine, that on macadam; covered with ½-in. powdered stone.	40
18.	Same when scraped clean with a shovel.	19
19.	Same when covered with ½-in. fine dust.	28
20.	Wood Block: Rectangular blocks, 3x12-in., considerably worn	36
21.	Round cedar block covered with ½-in. silica pea gravel.	90
22.	Exactly same as above with ¼-in. crushed gravel	50
23.	Round cedar block; clean; blocks slightly convex on top	53
24.	Round cedar block, 2 ins. plank, 2 ins. sand, clean; not worn.	37
25.	Same as above; clean; slightly worn	51
26.	Same as above; clean; considerably worn.	54

These experiments are classic; but as the [illegible] print of them in English is a brief extra[illegible] results in vulger fractions (as is the origin[illegible] writer believes the data to be worth repro[illegible] here. The table represents about 700 exper[illegible] Any vertical column shows the traction for a particular vehicle on the various road surfaces, and any horizontal line shows the traction on a particular road surface for different vehicles.

Table VI. shows data obtained by the [illegible]. The tractive power was determined with a Goldwin dynagraph, Fig. 1. The instrument consists of two long flat springs fastened together at their ends, and having their centers slightly nearer apart than their ends. One end of the apparatus is attached to the wagon, and the team is hitched to the other. The pull of the team causes the centers of the flat springs to approach each other. One spring supports a graduated disk, and the other is connected to an index arm which is pivoted at the center of the graduated disk. From one end of this index arm the pull can be read directly from the graduation. There are two extra index arms—one to indicate the maximum power developed, and one to indicate a rough average. The former (the right-hand one in Fig. 1) is simply pushed around by the main index arm and is left at the highest point. The latter (the middle one in Fig. 1) has a transverse slot in which plays a stud on the main index arm. When making an experiment the main index arm is continually in motion, and the position of the auxiliary arm roughly indicates the average power exerted. The end of the index arm opposite the graduated arc records the amount of traction upon a strip of paper which is wound from one cylinder to another by clock-work situated back of the left-hand lower corner of Fig. 1. The autographic record is much the more accurate result. Fig. 2 shows a back view of the instrument.

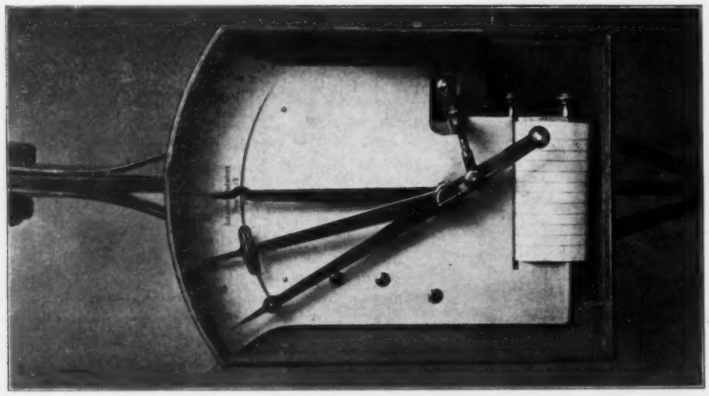


Fig. 1. Front View.

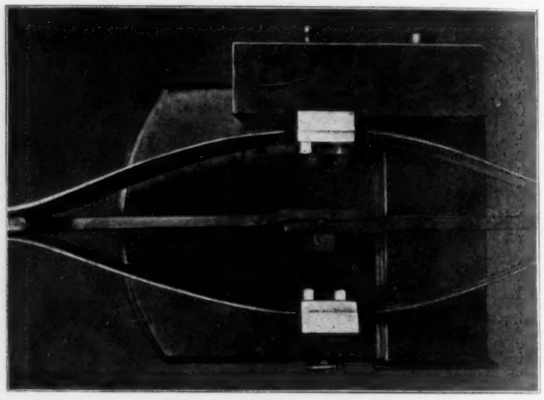


Fig. 2. Rear View.

DYNAGRAPH FOR WAGON TRACTION EXPERIMENTS.

TABLE V.—Traction of Different Vehicles on Various Level Roads, at Three Miles an Hour, in Lbs. per Ton.

Ref. No.	Description of the road surface.	No springs. Gun carriage. t = 4.5" a = 3". D = 60".	No springs. Freight cart. t = 4.5". a = 2.5". D = 64".	No springs. Freight cart. t = 4.5". a = 2.5". D = 80"	No springs. Artillery wagons. t = 3" a = 3" d = 45" D = 60"	No springs. Freight wagon. t = 4.5". a = 2.5". d = 36" D = 60"	No springs. Freight wagon. t = 4.5". a = 2.5". d = 44" D = 78"	On springs. Stage coach. t = 4.5" a = 2.5" d = 36" D = 56"	On springs. Carriage. t = 3" a = 2" d = 36" D = 56"	On springs. Wagon. t = 2.5" a = 2" d = 50" D = 58"
1.	Grass Plat: Very firm and dry	72	..	..	82	.	..	..	..	..
2.	Moderately firm	87	..	..	100	..	..	..	..	..
3.	A little moist	98	..	..	..	..	..	..	..	..
4.	Slightly wet	140	..	..	160	..	..	..	..	..
5.	Very wet, no water on surface	..	..	..	260	..	..	..	..	..
6.	Earth Road: Very good; nearly dry	57	55	44	66	74	63	77	76	64
7.	Covered with untrodden snow	109	105	84	125	140	120	146	..	123
	Gravel Road:									
8.	1¼—1½" loose gravel on firm earth	147	143	114	169	190	163	198	198	168
9.	2 —2½" " " " " "	172	168	134	198	225	192	233	233	198
10.	4 —6" " " " " "	185	180	144	216	241	206	250	250	212
11.	4 —6" " " and fine sand	196	190	153	247	251	217	267	290	225
	Broken Stone Road:									
12.	Good condition, dry and compact	32	30	24	37	40	34	42	41	35
13.	Very firm, large stones visible	37	35	28	43	47	40	49	48	41
14.	Little moist or little dirty	45	43	34	52	57	49	59	58	50
15.	Firm; little soft mud	57	55	44	66	74	63	77	76	64
16.	Firm; ruts and much mud	70	68	54	81	90	78	95	93	79
17.	Portions worn out; thick mud	83	80	64	96	107	92	112	110	94
18.	Much worn; ruts 3 ins.; thick mud	109	105	84	126	140	120	146	145	123
19.	Very bad; ruts 4" deep; very rough	121	118	94	140	157	134	164	168	139
	Stone Block Pavement:									
20.	Very smooth; narrow joints	25	23	18	29	31	26	32	31	26
21.	Fair condition; dry	27	25	20	31	34	29	35	34	29
22.	Moist; covered with dirt	34	33	26	40	43	37	45	44	38
23.	Plank Road: Thick oak bridge floor	37	35	28	43	47	40	49	48	41

t = width of tire; a = diameter of axle; d = diameter of smaller wheel; D = diameter of larger wheel.

The wagon employed was the usual thimble-skein four-wheel farm wagon, with a 2-in. tire. Experiments 3, 4 and 5 were made with wheels averaging 42½ ins. in diameter, and the remainder with wheels averaging 47 ins. Usually the pavements were known to be level; and where they were not, a trial was made in each direction, the mean being used to eliminate grade resistance.

Table VI. needs no explanation, but perhaps a few remarks are permissible.

1. ASPHALT.—Notice in experiments 1, 2 and 3 the effect of temperature upon the tractive power. The results are very astonishing, but seem to be in accordance with the opinion of teamsters. The driver for experiment 2 seriously objected to making the test, because "it is so hot that it will pull very hard on the asphalt." No. 2 is the mean of two trials giving practically the same results. No. 3 was checked by another experiment on another part of the same street, the result being the same to a tenth of a pound.

Experiment 2 was made at a walk (about 2½ miles per hour); and a test at a trot (about 5 or 6 miles per hour) over the same course gave 79 lbs. per ton. No. 3 was at a walk, and the same

course gave 61 lbs. per ton at a trot. It is recognized that the two tests are not consistent, but the only explanation suggesting itself is the difficulty of making tests at a trot.

2. BRICK.—Apparently these are the first traction tests ever made upon brick pavements. The result for No. 4 was the first made, and was so much of a surprise that the experiment was repeated at several places along the street—always with substantially the same result. The difference between Nos. 4 and 6 is surprising. Possibly part of the difference is due to the effect of traffic in smoothing the pavement. No. 4 is a year older, and also has the more travel.

3. GRANITE—The result of No. 10 was a surprise and therefore was carefully checked. None of the granite blocks experimented upon were much worn.

4. MACADAM.—Probably No. 13 can be regarded as the very best broken stone road.

5. STEEL WHEELWAY.—The results for this road were unexpectedly large, and are doubtless due to the deflection of the face of the track under the wheel. It is difficult to see how the wheelway in practice can be kept cleaner than in Nos. 18 and 19. Several questions naturally occur in this connection, but the discussion thereof is referred to the advocates of the steel wheelway.

In conclusion, the writer desires to acknowledge his obligation to General Manager Leonard and other officers of Union Stock Yards, Chicago, for valuable assistance in making the experiments in and near the Yards; to John B. Hittell, Chief Engineer of Streets, Chicago, for facilities in making the tests near the center of the city; and to Frank R. Crane, Instructor in Farm Mechanics, University of Illinois, for the manipulation of the dynagraph.

THE CONSTRUCTION OF THE ASPEN, WYOMING, TUNNEL ON THE UNION PACIFIC RAILROAD.

By W. P. Hardesty, C. E.*

In the original location of the main line of the Union Pacific Ry. from Cheyenne, Wyo., to Ogden, Utah, the aim was more to secure a cheap and easily built line than to secure the shortest possible route. As the Congressional act in aid of building the road allowed a bonus of so much per mile, there was also an obvious additional reason for not selecting the most direct line. Of late years the great increase in the number and weight of trains has made it very desirable to reduce the grades and curves, and, in common with many other Western roads, the Union Pacific has made many and extensive changes of this nature. These changes were projected soon after the road passed from the hands of receivers to its present managers.

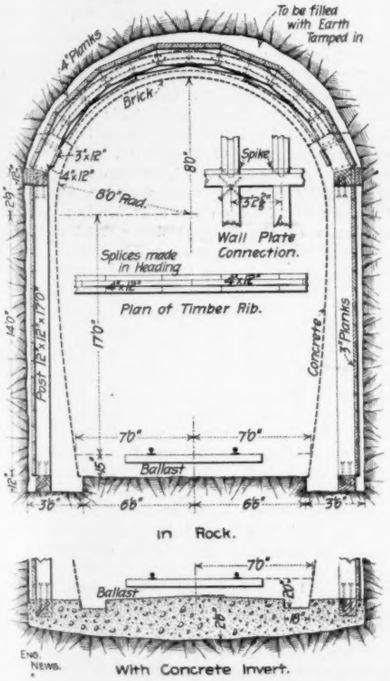


Fig. 2. Standard Section of Aspen Tunnel, With Timber Lining.

(The dimensions of this section were altered and other changes made after beginning construction, as is described in the text.)

*Progress Building, Salt Lake City, Utah.

Fig. 1. Sketch Map of Union Pacific Cut-Off from Leroy to Bear River, Wyoming, Showing Location of Aspen Tunnel.

J. B. Berry, Chief Engineer, Union Pacific R. R. Kilpatrick Bros. & Collins, Beatrice, Neb., General Contractors.

The prime mover in inaugurating and carrying through these recent improvements has been President Horace G. Burt, himself a practical engineer, and one fully appreciating the need of the changes. All of the work in Wyoming has been done since April, 1899. The following comparison of the old and new lines embraced in the eight distinct cut-offs or changes in the old line in Wyoming will give an idea of the extent of the improvement wrought:

	Old.	New.	Saving.
Length of line in miles	219.40	188.93	30.47
Max. grade in ft. per mile, compensated	45.4 to 97.68	43.3	..
Max. curvature, degree of curve.	3 to 6	1 to 5	..
Total angle, in degrees	11,187	4,458	6,729
Total curvature, in miles	71.03	42.16	28.87
Per cent. in curvature	32.37	22.31	.

Of the 188.93 miles given as new line, only 158.04 miles are entirely new construction. Of the eight cut-offs, one of the most important and the latest one to be built, is that reaching from Leroy to Bear River, shown by Fig. 1. This is the westernmost cut-off, and it is near the west end of the State, just east of Evanston. The line here crosses the Aspen ridge, a low range of mountains. The drainage from the west slope of this ridge leads to Great Salt Lake; that from the east slope leads to the Green River and finally to the Gulf of California. The old line makes quite a detour to the south to cross this range, and even then crosses at an elevation that requires a heavy grade to overcome. The new line is much more direct and requires less of a climb, but to secure these advantages it has been necessary to construct a tunnel of unusual length. The construction of this tunnel has developed so many interesting features that it will form the chief subject of this article.

The elevation of track at Leroy (the east end of the cut-off) is 6,770.3 ft. above sea-level; that at Bear River (the west end) is 6,974.6 ft. On the old line the summit was reached at Tapioca (two miles east of Aspen Station), at an elevation of 7,579 ft. On the new line the maximum elevation of track is 7,300.7 ft. at 1,600 ft. west of the west portal of the tunnel. The elevation of the summit of the ridge over the tunnel line is 7,746 ft. The east end of the tunnel is 11.5 miles from Leroy.

The course of the tunnel is a little south of west, and the length is just 5,900 ft. There is a descending grade of 0.4% from the point 1,600 ft. west of the tunnel eastward through the tunnel. To limit the length of the tunnel to 5,900 ft. required extremely heavy approach cuts. That on the east is nearly 2,200 ft. long, and it contained 250,000 cu. yds. of material. The depth of this cut at the portal is 72 ft. at the center, and at the north slope it is 132 ft. This approach is through the depression that forms the head of Pioneer Hollow, and the drainage naturally flows into the cut at and near the portal. A deep ditch is run entirely around the end of the cut to intercept this drainage. On the south side a large ditch is also built to divert the water coming from farther up the hollow, and also that from the hillside above it, and to carry it on beyond the cut. In this approach some trouble has been had with slides caused by water in the lower strata, the material being clay. To prevent this a ditch has been dug along the north side of the track and a line of 10-in. drain pipe has been laid, with cross branches for draining the bottom and south side of the cut. The approach cut on west end is nearly one-half mile long, but the length of very heavy cut is much less than on the east end. The amount of excavation was 177,000 cu. yds., of which 58,000 cu. yds. were solid rock. At the west end a permanent ditch was also dug around the end of the cut to intercept the drainage.

The material encountered in boring the tunnel has somewhat changed the original plans for the timbering of it. Nearly all the material is shale of carboniferous formation, with an occasional stratum of yellow sandstone. The dip usually ranges from 20° to 30°, and is to the east. The shale, much of it approaching soapstone, has proved to be very treacherous and difficult to hold in place. Much water has also been encountered, rendering the drainage of the tunnel during construction quite a problem.

The section of tunnel in solid rock (no lining) was intended to be 14 ft. wide at the bottom, 16 ft. wide at 14 ft. up, and the top or roof arch was to be made with an 8-ft. radius. This section would run 12.32 cu. yds. per lin. ft. No opportunity was offered to use this section. The standard section of excavation, where timber lining is used, is 20 ft. wide, 17 ft. 2½ ins. from top of ties to the springing line and 7 ft. 3½ ins. from the springing line to the top, which is made with an arch of 10½ ft. radius (Fig. 2). There were meant to be trenches 3½ ft. wide, one on each side, carried to 2 ft. 3 ins. below grade, but these have not been made. The bottom was excavated to 15 ins. below grade to allow for ballast and ties. The area of this ideal section is 483 sq. ft., running 17.88 cu. yds. per lin. ft. It allows 3 ins. outside of the 3-in. lagging or back of the timbers. It has been found difficult to restrict the tunnel section to the standard, so that, on an average for the tunnel, the amount of excavation has run about 1⅛ cu. yds. per lin. ft. in excess of the standard.

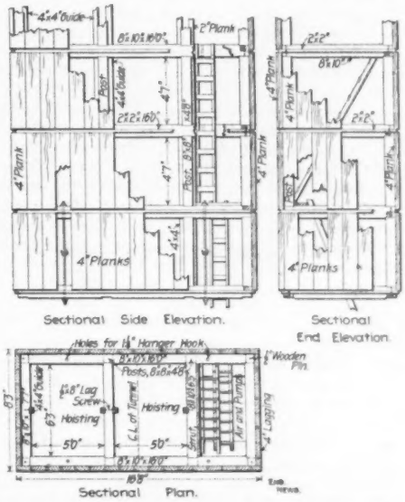


Fig. 3. Plan and Elevations of Timbering for Shaft of Aspen Tunnel.

Inside the timbers the dimensions are 17 ft. wide in the clear and about 22½ ft. from base of rail to roof, with posts 17 ft. long. The dimensions of timbers are shown by the plans. The wall plates are 16 ft. long, and the sills are from 6 to 8 ft. long.

The seven-segment arch used is undoubtedly

well suited for pressure that is mostly vertical, but it would be weak for the great side pressure here found if it were not for being built up in segments with broken joints. This greatly strengthens the arch against uneven pressures. In constructing the arch the pieces were first made into three main members, one for each side and one for the cap or crown. Then each side one was stood on its wall plate in correct position and temporarily held up. The center one took charge of it. The headings met at 1,000 ft. west of the shaft, or 1,850 ft. from the west portal. The following are the figures of the greatest monthly progress:

From east end	Heading,	306 ft. in August,	1901
" " "	Bench,	502 ft. in March,	1901
From west end	Heading,	203 ft. in July,	1901
" " "	Bench,	258 ft. in July,	1901

Fig. 4 is a view in one of the headings, showing the timber arch ribs in place. Probably about 15 to 18 ft. was the greatest length of heading remainder the posts are spaced 2 f... and for about 900 ft. the spacing was 1 ft. ... there was a solid row of the 12 × 12-in. timb... About 600 ft. of the latter were taken out f... the concreted portion of the tunnel. Very li... of this close spacing was used east of the s... The great difficulty in holding the sides ... roof of the tunnel was due to a lateral pres... which gradually forced the walls inward. Ev... solid wall of timbers was not proof agains... dis-

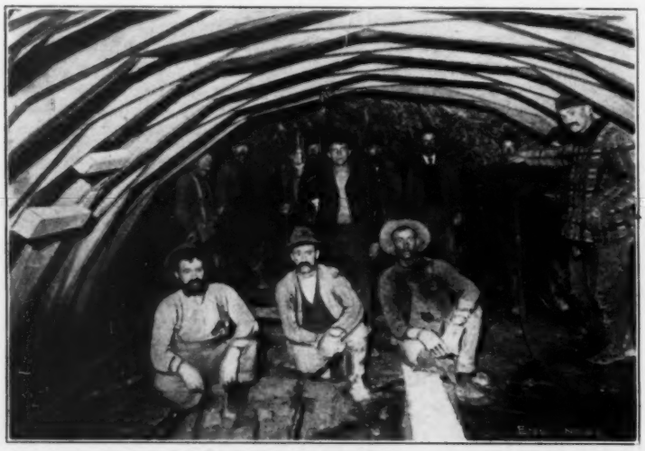


FIG. 4. VIEW OF HEADING, SHOWING SEGMENTAL ROOF ARCH RIBS OF TIMBER LINING.

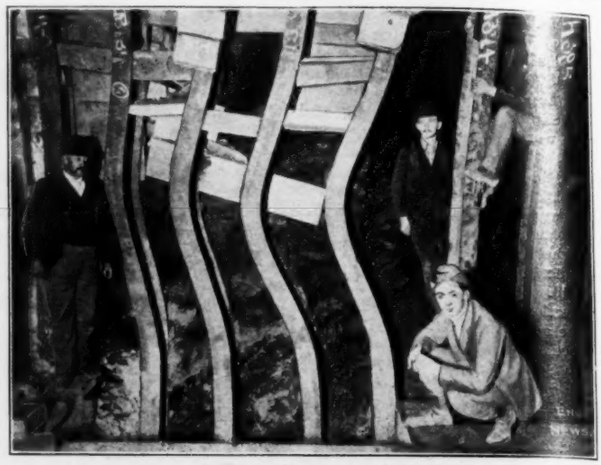


FIG. 7. VIEW SHOWING DISTORTION OF I-BEAM LINING RIBS BEFORE CONCRETE FILLING COULD BE CONSTRUCTED.

was then placed in position and the three spliced together along the joints shown in the drawing, Fig. 2.

Work was begun on the tunnel on Nov. 16, 1899, by starting to sink a shaft over the center line at 3,050 ft. from the east end. The dimensions and timbering of this shaft are shown by Fig. 3. No trouble was experienced until a depth of 257 ft. was reached. Here, on Feb. 3, 1900, a flow of water was struck that drove out the men. Pumping was started on Feb. 16, when the water was 126½ ft. deep in the shaft. It was cleared out in about ten days, and the sinking of the shaft was resumed. The use of air drills was begun on March 3, 1900. Many strata of hard, seamy sandstone, carrying much water, were encountered below the 257-ft. depth. On March 10 the flow of water was 48,000 gallons in 24 hours; on March 19 it was 65,000 to 70,000 gallons, and on April 1 it was over 101,000 gallons. Two pumps were now used. The roof of the tunnel was reached on April 20. A total of 1,780 cu. yds. of material were excavated for the shaft, and 103,000 ft. B. M. of lumber were used in timbering it. The depth from top of the shaft to the tunnel floor is 331 ft.

Headings to the east and west from the shaft were begun; but the water rapidly increased, and after driving each heading for about 250 ft. work was stopped on Aug. 11, 1900. The flow was then approximately 300,000 gallons per day, and was all that the pumps could handle. The heading at the east end of the tunnel was begun April 12, 1900, and the east bench on Sept. 17, 1900. The west heading was begun on March 14, 1900, and the west bench on July 13 of the same year. Work on this heading was begun without waiting to excavate the approach cut. A large pit had to be sunk to the proper level before beginning work. A temporary railway track was extended along the north side of the approach (on the surface of the ground) for the delivery of materials used in excavating and lining the tunnel. A dam was built just above the portal to intercept and hold the drainage that would otherwise flow down into the approach. The east heading met the one from the shaft on June 8, 1901. The main headings met on Sept. 8, 1901, and the bench excavation was completed early in October. The sinking of the shaft and the headings from same and the main east heading were under direct charge of Mr. Daniel Lyon. The work at the west end was also directed by him until September, 1900, when Mr. C. E. Higbee driven from the east end in any one day. The material encountered at the east end was much better to work in as a rule than that at the west end. The original intention was to have the sets

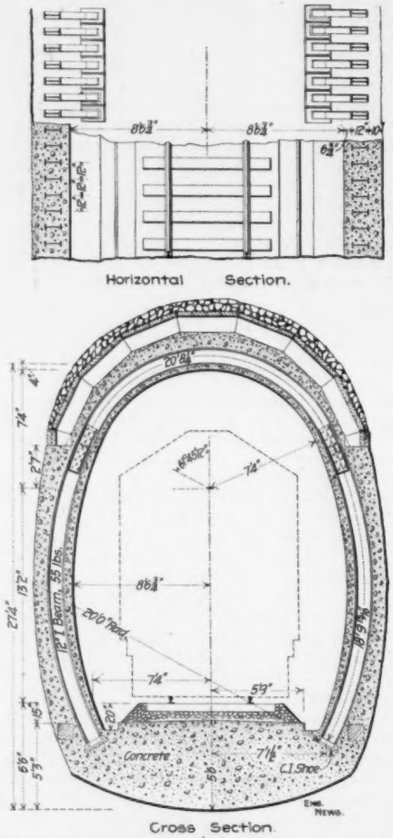


Fig. 5. Plan and Section of Concrete and I-Beam Lining.

of timbers spaced 3 ft. 2 2-5 ins. c. to c., or five to a 16-ft. length of wall plate. Only about 200 ft. of tunnel, adjoining the portals, permitted of this, however. For all but about 900 ft. of the torting pressure. Whether this was caused by a swelling of the shale due to oxidation by contact with the air or by the direct pressure of the overlying strata is a question not settled. The former seems to be the more probable cause. The inward movement of the shale walls and roof was slow (not over 1 in. per day), but was quite steady and sure. The sides of the timber sections were forced in, and the wall plates were compressed to not much over one-half their former thickness by the tremendous pressure on the arched sections above. In addition to the regular timber section, wherever the pressure was great, there was at each set a horizontal brace or strut reaching across the tunnel. This was of 8 × 10-in. and had its top 4 ins. above the top of the sill (against foot of the post), and its bottom 6 ins. below the same. These were mostly broken, possibly by the bottom heaving up, and possibly by the great load on the sills forcing them (and the ends of the braces) down, and so bending the braces over their more solid support along the middle. These braces have all been replaced by the 12 × 12-in. size, which do not allow of the side ditches that were intended for drainage.

For a portion of the tunnel the pressure was so great that a solid wall of timbers would not hold. For this portion the steel and concrete lining shown by Figs. 5 and 6 was used. It begins at a point 557 ft. from the west portal, and is 713 ft. long. The steel framework consists of 12-in. I-beams, weighing 55 lbs. per ft. and spaced from 12 ins. to 24 ins. c. to c., according to the pressure. Each I-beam bent is made of three pieces or segments. These were shaped by bending, the top or arch segment being bent to a circular curve, with 8 ft. 2 ins. radius, and the two side segments being bent to much flatter curves. The weight of each complete rib is 3,446 lbs. The height in the center is 20 ft. 10 ins. above the top of ties, and the greatest width is 18 ft. 3 ins. The steel is imbedded in concrete, which reaches inward to a depth of 4 to 6¾ ins. inside the bents and backward till a total thickness of 2 to 3 ft. is attained. The feet of the side I-beams rest on cast-iron shoes.

The concrete foundation extends across the tunnel and reaches a depth of 5½ ft. in the center, and is strengthened by a layer of old rails imbedded in it and reaching across the tunnel. The concrete is composed of one part cement, three of sand and six of broken rock. It was mixed outside the tunnel and hauled in on tram cars.

The amount of concrete averaged about 8¾ cu. yds. per lin. ft. The shape of the concrete section is an oval, 17 ft. 1½ ins. in greatest width at 7¼ ft. above base of rail, and 20½ ft. high from the base of the rail to the under side of the arch. The steel and concrete work was done by the railway company, being superintended by Mr. J. L. Neff, of Cheyenne, Wyo. It was very difficult and tedious work. The timbering was first removed, section by section, while the steel ribs were substituted for it, and then the concrete was placed. The movement of the rock was so slow that usually there was sufficient time for the concrete to set before pressure was brought upon it. The rock was temporarily held back by timber filling at the back of the steel ribs. Fig. 7 shows the effect produced on the ribs by the great inward pressure in one part of the tunnel before the concrete could be placed. Fig. 8 shows the method of constructing the concrete and I-beam lining. About six months was required for the work. The crushed timbers in this and other parts of the tunnel were hauled outside. Of the enormous quantity of this timber much was hauled away, some was used for fuel, and the rest was burned.

In excavating the tunnel the heading was taken out full size down to the line of the wall plates. The bench, of approximately 17 ft. depth, was then taken out in two lifts or layers. On the east end these were blasted out and the broken material shoveled or rolled down to within reach of the steam shovel. On the west end the material from the upper lift was usually run out on wheelbarrows (on a plank gangway) and dumped within reach of the shovel. The top lift averaged about 6 ft. in depth and the bottom one 11 ft. Most of the material on the east end was quite easy to drill.

The use of steam shovels to handle the muck from the benches undoubtedly did much to hasten the work and to lessen the cost of excavating the tunnel. The shovels, one of which is shown in Fig. 9, are of small size, having a dipper of ¾ cu. yds. capacity and a height of boom above the track of 16 ft. Though meant for steam, they are here operated by compressed air, at 60 to 100 lbs. pressure. The air works in the cylinders in the same manner as steam. Two men, an engineer and a craneman, operate one. They are moved on a track of 3-ft. gage. These shovels rapidly load the muck resulting from a blast.

At the east end the tramway was of 3-ft. gage. The cars were 12 ft. long and 6 ft. 9 ins. wide in extreme dimensions. The length of the box was 8 ft. 10 ins., the height from rail to bottom of box was 3 ft. 4 ins., and the depth of box was 2 ft. 2 ins. Each car held 3 cu. yds. These cars were made up into trains of 10 to 16, and hauled out by a "dinkey" engine weighing about 11,000 lbs. For the west end, horse tramcars of 2-ft. gage were used. These were 10 ft. long over all; the box was 5 ft. wide, and its bottom and top were 2½ ft. and 4 ft., respectively, above the rail. Each held from 1½ to 1¾ cu. yds.

At the west end, owing to the extreme distance to suitable dumping grounds below the level of the track, much of the muck from the tunnel was disposed of as follows: Near the portal a dugway was excavated in the slope of the approach cut, up which the 2-ft. gage tramway was extended. A hoist was erected near the top, and the cars were pulled up this and run out over the surface of the ground and dumped where desired. At the east side there was more embankment for which the muck could be utilized, and that not so used was wasted below grade.

At a point 1,600 ft. in from the west end, a slight flow of oil was struck on the north side of the tunnel. This was in sandstone. Natural gas was also found in considerable quantities. This could be ignited, and was the cause of a serious accident. A fire caused by it was burning up the timbering, when a bulkhead was erected between the fire and the end of the tunnel and plastered with mud to make it tight, with a view to smothering the fire. The gas entering this chamber became so dense that it ignited and exploded with tremendous force, knocking down the bulkhead. Four men were killed by the explosion. Other accidents, with several fatalities and injuries, have also attended the construction of the tunnel.

At the time of greatest flow of water, two Cameron pumps of 140,000 gallons capacity each and three smaller ones were in use. Ventilation was secured by an exhaust fan at each end of the tunnel, located directly over the portal. The foul air was drawn out through each fan by a large pipe reaching to a point near the heading. This pipe is shown running along the right-hand side wall in Fig. 8. Pure air was thus drawn into and through the tunnel toward the heading. This arrangement was found to be superior to the reverse one of forcing the pure air through the pipe to the heading. By the latter method the air would be contaminated by the fumes from the blasting and by the natural gas and smoke, and would have to be breathed by all the men working from near the heading back to the portal.

The supply of compressed air for working the air-drills for both headings and the shaft, the "steam" shovels and the ventilating fans has been furnished by a plant located about 3,000 ft. outside of the east entrance to the tunnel. Here there were two boilers of 150 HP. each and two of 100 HP. each. The compressor plant consisted of three Ingersoll-Sargeant piston inlet air compressors, one of size 24 ins. and 24¼ ins. by 30 ins. stroke, and one of 22 ins. and 22¼ ins. by 24 ins. stroke, all with a combined horse power of nearly 600. The air is conveyed as far as the mouth of the shaft in a 6-in. main, and from here to the west end in two 3-in. mains. At points where the pipe is tapped to draw off a portion of its supply, a small reservoir is placed to equalize the pressure whenever there is any sudden draft.

At the compressor plant there was also located the electric lighting machine. This was a 60-K-W. alternator. The voltage was 1,100, stepped down to 104 volts at points of use for incandescent lighting. The capacity was 1,000 lights. As many as 200 of these were used in the tunnel before the headings met, but a less number was required while finishing the benches.

Approximately, 4,500,000 ft. B. M. of Oregon fir was used in the lining of the tunnel and shaft.

OTHER WORK ON THE LEROY-BEAR RIVER CUT-OFF.

The cut-off is 21.61 miles long, all new line, and is 9.56 miles shorter than the old line. The maximum grade is reduced from 68.6 ft. per mile to 43.3 ft., and the maximum curvature from 5° to 3° 36'. The total of degrees of angle in curve is reduced from 2,017 to 646, and the total mileage in curve from 13.15 to 6.49. There are only six curves sharper than 2°, and they are all spiraled.

The total material placed in embankment was 1,902,000 cu. yds. The total of excavation, not including that in the tunnel, was 1,173,800 cu. yds., of which 541,200 cu. yds. were solid rock. Only two classifications, that of earth and solid rock, were allowed. There is one fill 3,600 ft. long and containing 184,000 cu. yds. The maximum height of fills is 50 ft. The largest cut is 2,300 ft. long and it contained 30,000 cu. yds. of solid rock and 68,000 cu. yds. of earth. The maximum depth of this cut (measured in the center, as in fills) is 80 ft. The roadbed is 20 ft. wide in fills, and in cuts it is excavated to 25 ft. width, to allow of a 3-ft. ditch on each side. Cuts were taken out on slopes of 1½ to 1, as in all the new work in Wyoming. This is an unusually flat slope for railway work.

For culverts, cast-iron pipe is used up to 36 ins. diameter. Where a larger opening than this is required, a concrete arch culvert is used. American Portland cement is used in these, and they are fine examples of work. There is one with a 20-ft. span, and there are four others of 15-ft. span. The crossing of Stowe Creek, just above where it joins the Bear River, is made by a 50-ft. plate girder span. This is supported by heavy concrete abutments, about 35 ft. high, which are founded on piles. The cost of the substructure was very much more than that of the superstructure. The crossing of the Bear River not far above Bear River Station (Station No. 4) is made by a 140-ft. lattice truss bridge. All the bridges on the revised lines in Wyoming have been calculated for a load consisting of two 172½-ton consolidation engines, followed by a

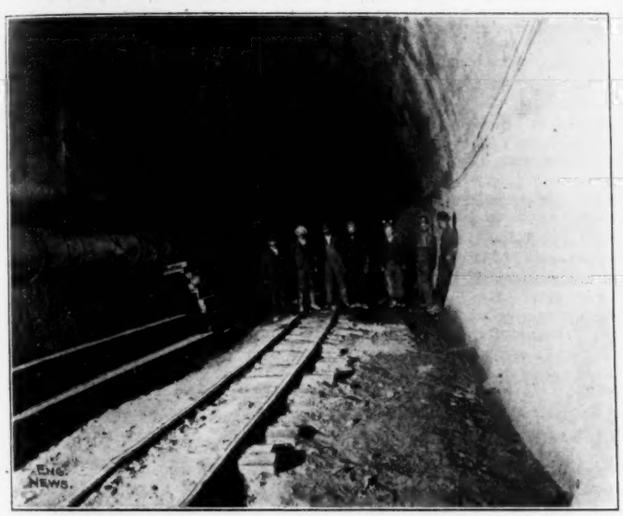


FIG. 6. VIEW SHOWING APPEARANCE OF FINISHED CONCRETE AND I-BEAM LINING.

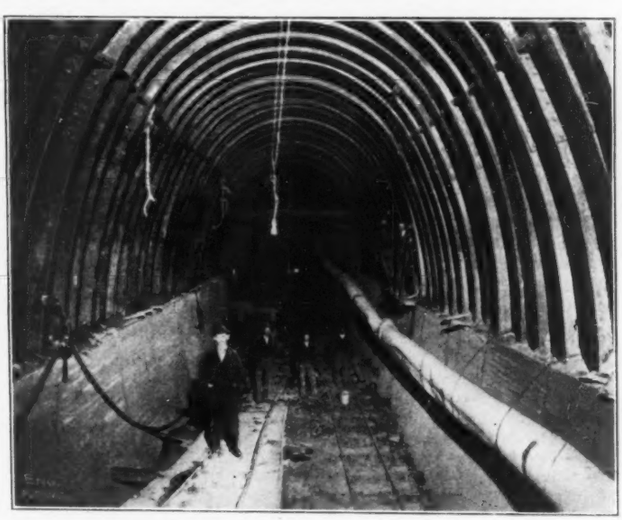


FIG. 8. VIEW SHOWING I-BEAM ARCH RIBS IN PLACE AND CONCRETE FILLING COMPLETED PART WAY UP ON EACH SIDE.

train load of 4,000 lbs. per lin. ft. The iron work was furnished (assembled as far as practicable) by the Lassig Bridge Co., of Chicago, and the erecting was done by the railway company.

The ballast used on the Leroy-Bear River cut-off came from the pits at Granger, 43 miles east of Leroy. It is very coarse, many of the pieces being 4 or 5 ins. long and 3 ins. through. Though said by some to be a difficult material with which to make a good bed with, it seems to answer well enough here. There is plenty of small and fine gravel along with the coarser. The material used in surfacing station grounds came from the pits on Sherman Hill. This celebrated ballast material is a disintegrated granite, with small, angular pieces, and is extensively used as far east as Omaha and as far west as Rawlins by the railway company. A depth of 15 ins. of ballast is used 8 ins. under the 7-in. ties. The width on top is 11½ ft. The ties are 7 × 8 ins. by 8 ft. All the ballasting and track-laying is done by the company itself.

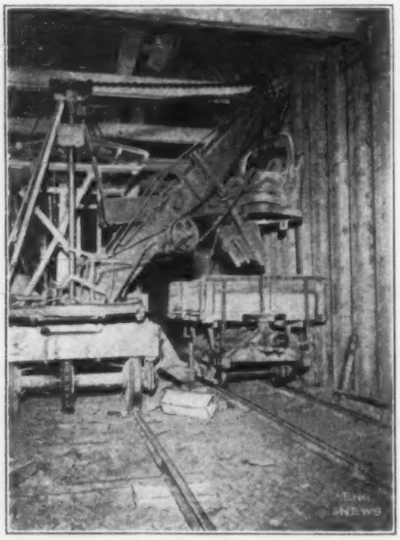


Fig. 9. View Showing Steam Shovel Used for Loading Blasted Rock onto Cars.

The new track is laid with 80-lb. rails, and tie-plates are used on all curves of 3° or sharper. The tunnel was completed early in October, 1901. The track had been laid up to the portals, and shortly before finishing it was laid in the tunnel up to near where the remaining bench was being excavated, but to one side of the center, so as to avoid interference with the tramway. When the excavation was completed, the tramways were taken up and the main track thrown over to the center. Regular trains began running through shortly before midnight, Oct. 15.

The contractor for this cut-off, and for nearly all the other work in Wyoming, was the firm of Kilpatrick Bros. & Collins, of Beatrice, Neb. Mr. S. D. Kilpatrick was in general charge at Aspen for most of the time. Mr. Daniel Lyons was general foreman for all the tunnel work, except that done at the west end for a little over a year previous to completion. Great credit should be given to Mr. Lyons, to whose skill, energy and indomitable perseverance is mainly due the rapid completion of the tunnel against such great difficulties. Mr. Higbee, who had charge at the west end for a year, is also a veteran in the work of driving tunnels, and had charge of several important pieces of work before his connection with this one. The resident engineer in charge of the cut-off was Mr. K. C. Weedin. The division engineer in charge of the three miles of line including the tunnel was Mr. W. S. Woodworth. Both of these gentlemen have performed in excellent shape the responsible duties put on them. This and all the other work has been in general charge of Mr. J. B. Berry, Chief Engineer, and Mr. R. L. Huntley, Principal Assistant Engineer, of the Union Pacific R. R. Co.

CONCRETE ROADBED CONSTRUCTION FOR STREET RAILWAYS.

With the rapid development of traffic on electric street railways and the introduction of the modern heavy cars, it has become necessary to adopt a track construction of such weight and stability as to enable it to sustain the traffic without involving undue expense for repairs and maintenance. It is coming to be more generally recognized, however, that the track (in city streets, at least) should be considered as a part of the street paving and should be built and maintained with that paving. No city has as yet gone so far as to build the tracks with the pavement and lease them to a railway company for operation, which would be the logical method under an advanced system of municipal administration. Several cities, however, now exercise more or less authority over the character of track construction, but this is naturally not quite approved of by the railway companies, which consider their own particular requirements rather than those of the users of the streets as a whole. One great difficulty in the maintenance of a permanent track construction (and pavement) is that streets are liable to be continually torn up for the laying of water or gas mains, sewers, electrical conduits, etc., and for the laying of lateral house connections by plumbers, etc. The trenches thus made are rarely properly filled so as to prevent settlement, and consequently the foundation of the streets as well as its paving is injured. In only a few cities have steps yet been taken to check this injury to public property.

In regard to the roadbed construction of street railways, it is now generally recognized that the best practice in city streets is to provide a concrete foundation, while for suburban lines or the less important streets with light traffic a bed of gravel, slag or broken stone, well rolled, may be laid as a base for the ties. The subgrade should be well rolled, and the bed of gravel or other material also rolled so as to consolidate it and prevent settlement, as there will be no opportunity when the paving is laid for the continual surfacing, lining, tamping of ballast and tightening of bolts and spikes, which forms a large part of the maintenance work on ordinary railway track. In some cities it is still the practice to simply excavate to a depth sufficient to lay the ties directly upon the subgrade and to fill in between the ties with earth or gravel, or sometimes concrete, to support the paving. This is poor practice, however, for city streets, as it usually results in a rough riding track and a defective pavement, with consequent heavy expenses for repairs and renewals.

We give below the details of roadbed construction for street railways in a number of large cities, in all of which concrete is used to a greater or less extent. It has been claimed that a concrete base makes the track too rigid, causing wear of wheels and rails and hard riding of the cars. This is not the case with proper construction, however, as is shown by the experience in some of the cities noted below and by the experience at Scranton, Pa., noted in our issue of D[illegible] 26, 1901. The tracks on the approaches to the Brooklyn Bridge are laid upon concrete, and have worn extremely well under a traffic of some 4[illegible] cars per day, the grade being 3%. No ill effects upon the wheels or rolling stock have been observed, while the wear of the rails and joints is reported as being undoubtedly better than it would have been with wooden cross-ties. Where a concrete foundation is used, it may be in the form of a separate longitudinal beam or stringer to each rail, or a continuous sheet of concrete across the street. The former plan is specially economical for new lines in streets already paved and having either no concrete foundation at all or one which, while thick enough to carry the street traffic, is not thick enough to support the track.

KANSAS CITY, MO.—Fig. 1 shows the concrete beam system as employed by the Metropolitan Street Ry. Co., of Kansas City, Mo. A trench is dug for each line of rails, 20 ins. wide at top and 16 ins. at the bottom, which is 6 ins. below the level of the rail base. Wooden blocks, 8 × 10 × [illegible] ins., are placed in the trenches 10 ft. apart, the rails being spiked to the blocks and temporarily spliced. The blocks are only to support the rails while the concrete is being laid. The track is then adjusted to line, gage and surface, after which the trenches are filled with concrete, tamped well under the rails to give them a full bearing, and allowed to set for about six days, according to the weather, as it will set more quickly in warm than in cold weather. The concrete is composed of 1 part Portland cement (by measure), 1 part natural cement, 4 parts sand and 10 parts crushed stone. It is put around the rails before the cast-weld joints are made, in order to protect the rails from the effects of changes of temperature. In constructing this system on existing double-track lines, a section of about 1,000 ft. of one track is temporarily closed to traffic, portable cross-overs connecting the tracks at the ends of the section.

In view of the claims made to the effect that a rigid concrete base will cause more rapid wear of rails and wheels, and also make a hard riding track, Mr. E. Butts, Chief Engineer of the company, has taken molds of several rails on a line which has both the concrete stringer construction and the wooden cross-tie construction. This line had been in operation about three years. Rails on these two systems on similar grades showed a hardly perceptible wear on the down-hill tracks, while on the ascending tracks the rails in both cases showed a wear of about 1-32-in. He was unable to detect any advantage in favor of the cross-tie system as far as rail wear is concerned. Nor does he think the wheels are affected, while much of the trouble due to hard riding can be attributed to deficiencies in the car springs. As a general thing, too little attention is paid to these springs, although they affect the durability of the rails and may make all the difference between a hard riding and an easy riding car.

BUFFALO, N. Y.—A system of construction somewhat similar to that at Kansas City is employed by the Buffalo Ry. Co., but the rails are temporarily laid on wooden cross-ties instead of blocks. This is shown in Fig. 2 for an asphalt street, with first-class stone block paving between the rails and in the "devil" strip between the tracks. The 9-in. girder rails, 60 ft. long, are drilled for tie-rods 10 ft. apart and for one bolt at each end for temporary splicing. They are laid on oak ties 5 × 7 ins., 7 ft. long, spaced 5 ft. apart, alternate ties being tamped with stone ballast. The track is then surfaced, gaged and lined.

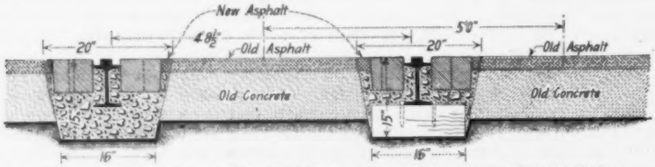


FIG. 1. STREET RAILWAY TRACK WITH CONCRETE STRINGERS; METROPOLITAN RY.; KANSAS CITY, MO.
E. Butts, Chief Engineer.

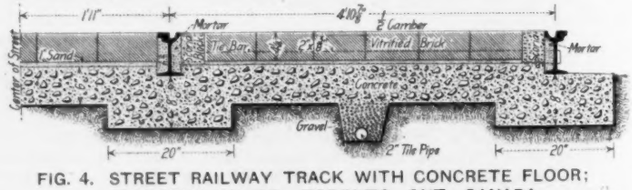


FIG. 4. STREET RAILWAY TRACK WITH CONCRETE FLOOR; TORONTO RY. CO., TORONTO, ONT., CANADA.

The alternate ties are then embedded in concrete, well tamped, and a concrete stringer 8 ins. deep and 15 ins. wide is formed under each rail. The use of broken stone under alternate ties is to facilitate the work, as the track can be adjusted to line and surface much more easily in this way than when concrete is used. Where first-class block paving is to be laid, the spaces between the ties and for 2 ft. outside the rails is filled with a 6-in. bed of concrete, but for common stone block paving sand filling is used instead of this concrete, as shown in Fig. 3. All concrete is composed of 1 part of Portland cement, 3 parts sand and 5 parts broken stone. The concrete stringers are allowed to set for 72 hours, the splice bars being then removed and the joints electrically welded.

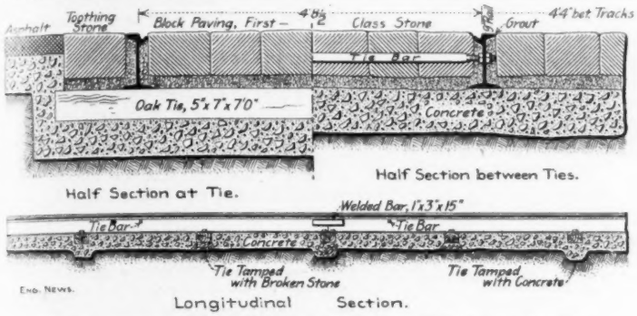


FIG. 2. STREET RAILWAY TRACK WITH CONCRETE FLOOR; BUFFALO RY., BUFFALO, N. Y.
C. C. Lewis, Engineer of Ways and Buildings.

Under this system 2,500 ft. of single track can be laid in a day, and there is no complaint as to its being too rigid. Mr. C. C. Lewis, Engineer of Way and Buildings, writes us that the surface and alinement are perfect, and that the track is apparently in as good condition as when it was first laid. Two years' experience is not enough to enable judgment to be pronounced, but it is believed that except for the wear of the heads of the rails the track laid in concrete will be as good in ten years as it is now. One cause working to the detriment of the track is the continual undermining by plumbers, gasfitters, etc. The company is unable to control their work in the vicinity of the tracks, with the result that trenches are continually being built under the roadbed, and as these are not properly back-filled, the track is bound to get out of service eventually. At present the surface is almost perfect, and it is practically impossible to detect the joints by sight or by riding in the car.

On some of the older lines of the company's system, acquired from the Buffalo Traction Co., a rather different style of construction was adopted. Concrete stringers were built and allowed to set, after which the rails were laid on steel ties resting on the stringers, the space between the rail and stringer being packed with grout. This track does not maintain good line or surface, and takes much longer to build, as only 500 ft. could be laid in a day. The unsatisfactory condition is attributed partly to the fact that the city engineer, when the lines were built, insisted upon grades for 9-in. rails that were not practicable, but more particularly because the rails and ties were not bedded in the cement beam, but were merely imposed upon it, the space between rail and beam being simply grouted. This may have advantages at times, as, for instance, where it becomes necessary to raise the grade of the track. This did occur once, and it was found that the ties and rails were easily lifted from the beam and placed at any desirable level above it. In this particular case it was an advantage, but the more important end of maintaining the rails in line and surface is not obtained by this system.

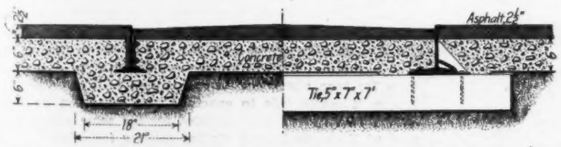


FIG. 5. STREET RAILWAY TRACK WITH WOODEN TIES AND CONCRETE; INDIANAPOLIS STREET RY., INDIANAPOLIS, IND.

All of the construction of the past two years within the city of Buffalo has been of 9-in. 90-lb. rail, or of 6¼-in. 60-lb. rail, and the method first above described has been followed in laying each kind. In Lockport the company has laid 85-lb. T-rails of the Am. Soc. C. E. section in macadam streets, using crushed stone 5 ins. under the ties and to within 3 ins. of the top of the rail, topping off with gravel and stone screenings for the new street surface. The ties were 2 ft. apart. In interurban work it has built 20 miles; width of roadbed, 16 ft.; oak ties, 6 × 9 ins. by 8 ft. long, 2 ft. c. to c. The rails are 60 ft. long, laid with suspended joints. The track was first surfaced with gravel, then back-filled with crushed stone, which the following spring was tamped under the ties and then more stone back-filled. The culverts, cattle passes and bridge abutments are mostly of concrete.

DETROIT, MICH.—This city, with over 140 miles of street railway (reduced to a single track basis), has practically all the tracks laid on concrete, with oak or steel ties embedded in the concrete. Asphalt and brick pavements laid on streets having car tracks are maintained in good condition, except in some cases at switches and crossings, where the pounding of heavy cars has its effect. Experience has shown that a concrete foundation under the tracks ensures a smooth and easy riding track, while the rigidity of the track due to the concrete base and the girder rails prevent the destruction of the pavement adjacent to the rails.

The concrete beam construction has been employed with successful results, the rails being laid directly upon the concrete and connected by tie-rods at intervals of 10 ft. The beam under each rail is 12 ins wide at the top and 18 ins. at the base, with a thickness of 8 ins. It is said that the alinement was better maintained with this class of construction than when the rails were laid on wooden cross-ties on a 6-in. bed of concrete. Steel rails are used on some lines. With block paving, the concrete street foundation would help to carry the load, but with asphalt paving and deep girder rails the concrete beams would be entirely below the street foundation. This system of construction is specially advantageous where new tracks are to be laid in paved streets, as it reduces the amount of work and material very considerably. It will be noted that the concrete stringers are of different section from those at Kansas City and Buffalo.

TORONTO, CANADA.—In this city two systems are used, both having a concrete bed, but in the one case wooden ties are used, while in the other they are dispensed with and the rails are laid directly upon the concrete. In the former construction the ties are laid on 4 ins. of gravel, a central trench having been also excavated and filled with sand after a pair of 2-in. tile drains have been laid. There are 1,800 cedar ties per mile, and between and over these is concrete, 10 ins. thick above the gravel. The concrete, however, is not carried below the ties, and the result has been in many instances unsatisfactory, as might be expected. On the ties are laid 6½-in. 73-lb. grooved girder rails. A line of granite or scoria blocks (alternate headers and stretchers) is laid along each side of each rail, and the rest of the surface is paved with asphalt, with a camber of ½-in. to each track. In the more recent type of construction, shown in Fig. 4, the entire width of the street is given a concrete foundation 6 ins. thick, increased to 8 ins. for a width of 20 ins. under each rail, a groove 1 in. deep being formed in the concrete to receive the rail base, which is laid directly upon the concrete. Grooved girder rails

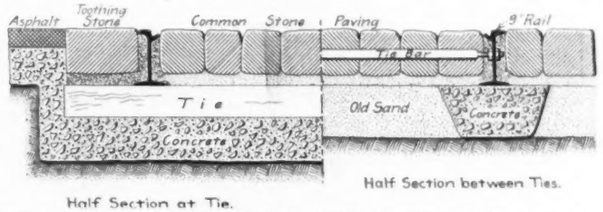


FIG. 3. STREET RAILWAY TRACK WITH CONCRETE STRINGERS; BUFFALO, N. Y.

are used, 6½ ins. high, with a line of scoria paving blocks laid along the inside of each rail, the rest of the paving being 4¼-in. vitrified brick on 1 in. of sand. Mortar is packed between the rail and the paving, but tile blocks are sometimes used for this purpose. Tie-bars ⅞ × 2 ins. are set 6 ft. apart, the threaded ends passing through the webs of the rails and being held by nuts on each side. There appears to be no objection to the rigidity of the track.

ROCHESTER, N. Y.—A somewhat similar system to that at Toronto, but with steel ties in addition, is used at Rochester, N. Y., as described in our issue of Jan. 5, 1899. Trenches 12 to 16 ins. wide are made, and the bottom covered with 4 ins. of coarse broken stone. A concrete foundation is then laid, 6 ins. thick, increased to 10 ins. at the ties and to 17 ins. for a width of 12 to 16 ins. under the rails. The top of the concrete is ½-in. above the base of the rail. The rails are of 6-in. 86-lb. grooved girder section, with ties of old inverted girder rails 6 ft. apart. On double track every joint tie and every third tie is 16 ft. long, holding all the rails. The rails on concrete have no objectionable effect upon the traffic.

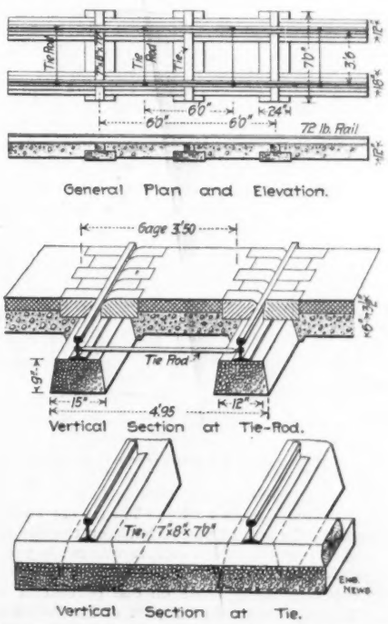


Fig. 6. Street Railway Track with Wooden Ties and Concrete; Denver Consolidated Tramways Co., Denver, Colo.
John A. Beeler, Constructing Engineer.

INDIANAPOLIS, IND.—A combination system,

with wooden ties and concrete stringers is used by the Indianapolis Street Ry. Co., as shown in Fig. 5. The wooden ties are laid 6 ft. apart, with brace plates on each tie. Above the ties is a 6-in. bed of concrete, embedding the rails and forming a foundation for the asphalt paving, while the thickness is increased under the rails to form stringers 6 ins. deep. The use of brace plates on every tie makes it unnecessary to employ tie-

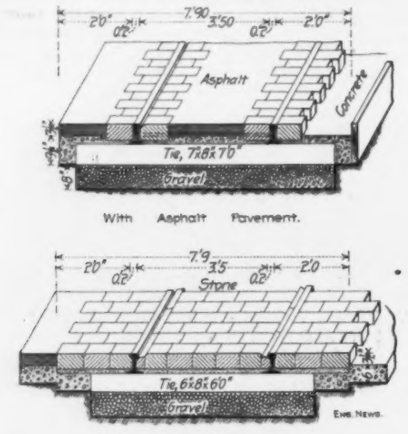


Fig. 7. Street Railway Track with Gravel Foundation and Wooden Ties; Denver Consolidated Tramways Co.

rods, but in some cases timber is dispensed with and the rails are bolted to steel ties. Where wooden ties are used, as above described, they are sometimes removed when the concrete stringers are hard, and the trenches thus left are filled with concrete. The experience with this construction is that it makes a very smooth riding track, with very little wear on rails, joints, wheels and rolling stock.

DENVER, COLO.—The Denver City Tramway Co. has a small amount of track laid with rails placed directly upon the concrete, as shown in Fig. 6. The rails are of T-section, 6 ins. high, weighing 72 lbs. per yd., and are spliced with six-bolt angle bars 36 ins. long. Ties are used 6 ft. apart, alternating with tie-rods 6 ft. apart. These ties are left in place permanently. The rails are spiked to the ties, which are blocked up to proper surface and line. The concrete stringers are 9 ins. deep, 15 ins. wide at the base and 12 ins. wide on top. They were built in forms made by planks placed between the ties and blocked in position. The concrete was made partly of 1 part of K. B. & S. Portland cement to 5 parts of gravel and sand, while on one portion of the work it was composed of 1 part of Louisville cement to 3 parts of gravel and sand. This type of construction is specially advantageous for new lines in streets already paved, as it can be built without disturbing the whole width of the street, but it is difficult to resurface when sags and settlement occur at excavations for water, gas and sewer pipes, etc.

The company has a considerable amount of its track built as shown in Fig. 7. The T-rails are 60 to 62 ft. long, laid on creosoted ties 7 × 8 ins., 7 ft. long, placed 24 ins. c. to c. on a bed of gravel rolled to a thickness of 8 ins. Concrete is filled in between and beyond the ties to form a support for the asphalt or granite block paving, as shown. After three years' service the paving and track were in good condition, and Mr. John A. Beeler, the Constructing Engineer, considers that under the local conditions this type of construction will last as long as any other.

Concerning the experience with concrete beam construction in comparison with tie construction on gravel ballast foundation, Mr. Beeler writes us as follows:

> Concrete construction costs 10 to 15% more and there is no way to repair the beam economically and cheaply when undermined by cuts for water and gas pipes, sewer work or other underground construction. Our maintenance, however, on both classes of work has been practically nothing as we have been fortunate in having little or no track undermined as yet. As to the durability, we estimate that there would be but little difference, as either type of construction ought to last as long as the life of the rail under similar traffic conditions, providing that the concrete beam was not undermined.
>
> As to the riding of the cars, only those who know of the difference in the construction can notice it on our lines. When riding on the concrete, cars seem to make more of a ringing sound, which seems to indicate more rigidity in the track construction. The paving shows no perceptible difference whether over the ordinary tie or concrete construction. I would not consider it advisable to remove the ties that are placed every 6 ft. (to replace them with concrete), especially in new construction work; although to lay a new track in streets already paved, where only a trench need be excavated for each rail, ties would not be necessary.

CINCINNATI, O.—In this city the track construction and the forms of rails to be used are prescribed by the Board of Public Service, of which Mr. H. J. Stanley is Chief Engineer. Various shapes of rails have been laid in the past, as noted in our issue of July 11, 1901, but the form now in general use is Section No. 109 (340) of the Lorain Steel Co., weighing 109 lbs. per yd., and known as the Trilby rail. This is considered good for the streets and for the operation of the electric cars. Fig. 8 shows the form of rail and joint. The rail is 9 ins. high, 5 ins. wide over the base and 5¼ ins. over the head, with a flaring groove 1⅛ ins. deep. The guard side of the groove is 1-16-in. lower than the running side or tread. The splice bars are 26 ins. long, with eight 1-in. bolts in two rows, the bolts being staggered. The rails are spiked to oak cross ties at intervals of 10 ft., and are connected by tie-bars 5-16 × 1½ ins., 5 ft. apart, bolted to the rails.

The rails are embedded in concrete stringers, 9 ins. deep below the base of the rail, and extending 3 to 6 ins. above the base, while the width is from 18 ins. at the top to 16 ins. at the bottom. The concrete is made with Portland cement and limestone. The street has a 6-in. concrete foundation

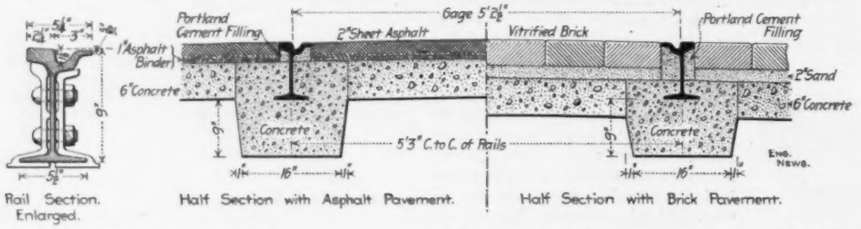


FIG. 8. STREET RAILWAY TRACK WITH CONCRETE BEAMS AND GROOVED GIRDER RAILS; CINCINNATI, O.

made with natural cement and limestone. This is covered with a 2-in. bed of sand for vitrified brick paving, or with a 1-in. asphalt binder course for a 2-in. surface of sheet asphalt. A filling of Portland cement is packed under the rail head, as shown.

This concrete beam construction is considered the best and the most permanent, although it is comparatively new in this city. Wooden tie construction is also used, with broken stone ballast in macadamized streets and concrete ballast in paved streets. This appears to be substantial. There is also some track with metal ties; this has been laid about five years and seems to be holding up well under the traffic.

MILWAUKEE, WIS.—In this city the city engineer exercises authority over the character of the street railway track construction, but while a grooved rail is recognized as the most advantageous, its use has not yet been enforced by the city. The tracks are built with a concrete foundation whenever the city lays a permanent pavement, such as asphalt, brick or stone, on a concrete foundation. The practice is to lay 6 ins. of concrete under the ties, upon which is laid a 6-in. 72-lb. T-rail. On streets paved with asphalt a line of granite blocks 5 × 18 ins. (alternately headers and stretchers) is laid on each side of each rail, the inner rows having the edge next the rail beveled to form a groove. As the blocks are laid upon the concrete base, they are not liable to be tilted or displaced, but to prevent any tendency to tilt the long stretcher blocks, an experiment has been made with blocks 5 × 8 ins. and 5 × 5 ins., laid alternately. The stone blocks are paid for by the street railway company, and this construction has proved very satisfactory both to the city and the company. It makes a smooth but not a hard riding track. So far there has been no track construction without ties, and it has been suggested that if the concrete beam or stringer system should be used a layer of asphalt or mastic at least ½-in. thick should be laid on top of each stringer, to give the rail a good, even bearing, and at the same time make an easy riding track. The experience in other cities, however, appear to show that the rails may be laid directly upon the concrete without causing trouble, and it is doubtful if a composition could be obtained which would be soft enough to act as a cushion without being so soft that the rails would sink into it under the influence of heavy traffic.

COST OF BUILDING MACADAM ROADS AT PORT HURON, MICH.*

By Frank F. Rogers.†

As the cost of a given road depends, first on the amount of grading and draining necessary to prepare a suitable grade for receiving the metal, and as the amount of metal required to produce satisfactory results on any road depends both on the volume of travel and character of the soil that must sustain the covering, the following brief description of the two roads in Port Huron whose cost is given in this paper may be of interest to the reader.

Twenty-fourth St. is mostly sand and sandy loam, which in some places inclines to clay, all overlying a clay subsoil. The street was well turnpiked before the work of improving began, the center ranging from 2 to 3 ft. above the side ditches. No turnpiking or under draining being required, the work of grading was all confined to shaping a bed for the stone in the manner described below.

Dove St. is all sand. About 700 ft. of it was very flat with inadequate side ditches and this portion was entirely broken up and regraded, the ditch being trimmed to line and grade to conform to stakes set for that purpose before the work of shaping the stone bed began. No under drains were used.

The cost of a given road is always a local question, to be determined by the prices of labor and materials in its immediate vicinity, but in Michigan there is a fairly uniform supply of materials within a moderate railway haul and the price of labor varies within narrow limits. St. Clair county, in which Port Huron is situated, has no local stone of any consequence and has to pay in addition to the cost of its material a freight rate of 40 cts. per ton on cobble stones. Freight on the crushed quarry stone has thus far been about double the rate on cobbles. For this reason it seems safe to conclude that what can be done in this locality can be duplicated for the same cost in any part of Michigan having similar railway facilities.

The items of expense in any well-built road should be as follows: 1, Surveys and plans; 2, grading, including drainage and shaping; 3, purchasing or preparing the metal; 4, applying the metal to the road, including transportation from cars or crushers; 5, compacting, which will consist of watering and rolling. It has been my duty in the past few months to superintend the construction of two pieces of typical country road. There was no attempt to make these roads cheap by slighting necessary details, for they were built on account of the Port Huron Engine & Thresher Co.'s statute labor tax, with the right to charge a good rental for all the machinery employed, yet they were built with a view to making a given amount of money cover as many lineal feet of road as is consistent with good construction. They were built so far as possible with the machinery manufactured by this company, for the purpose of determining the efficiency of this machinery in the actual work of road building.

The accompanying tables give the cost of the two roads.

LAYING OUT AND GRADING.—The center line of 24th St. was run and stakes set 100 ft. apart, uniformly 12 ft. on each side of the center line, making the sakes 24 ft.

*Abstract of a paper read at the annual meeting of the Michigan Engineering Society, at Grand Rapids, Mich., in January, 1902.

†Civil Engineer, 1436 Lapeer Ave., Port Huron, Mich.

apart on a cross-section of the road. Levels were taken on the center line and on each side and a profile of the street prepared. The side ditches were in good order and, in fact, a very well graded road was found, so that about all of the work was, to prepare a suitable bed for the stone, and to put the shoulders in shape to hold the stone in place. No under drains were necessary.

The stone was placed 9 ft. wide on the central portion of the road. The work of shaping was nearly all done with a common road grader. This was first used to cut off the high places and fill the hollows by setting the blade at right angles to the line of street, locked in position and at proper height to cut and fill to the best advantage and used in this manner till no further good could be accomplished. The grader was then set with the blade at a slight angle and enough earth crowded to each side of the central 9-ft. strip to form suitable shoulders and make the desired crown to the bed.

into sharp competition with limestones furnished by the Michigan quarries. The following table (condensed—Ed.) will show the cost of crushing cobble stones at Port Huron in 1901:

Cost of Crushing Cobble Stones, Port Huron, Mich.

	July and August.	October and November.
Hours run	171.5	94
Stone crushed, cu. yds.	1,145	522
Labor cost	$254.08	$145.64
Rental cost	$133.00	$84.00
Fuel, oil and repairs, cost	$42.00	$37.00
Total cost	$429.08	$266.64
Cost per cu. yd.	30 to 50c.	34c. to $1.74
Ave. yds. crushed per hour	6.67	5.55
Ave. rental cost per yd. for crushing	12.5c.	16c.
Ave. total " " " " "	37.5c.	51.08c.
Ave. labor " " " " " (including fuel, oil and repairs)	25.0c.	35.00c.

Note.—In October and November, the total number of cords of stone crushed was 91.5, yielding 522 cu. yds. of stone at the crusher before crushing, cost 88 cts. We now will have the complete cost per cubic yard of stone in the bins of the crusher as follows:

Machinery cost, being interest and depreciation	$0.04
Labor cost, including fuel, oil, and repairs	0.25
Cost of stone per yard	0.88
Total cost	$1.17

Taking into account the ease with which stone from the crusher bins are loaded to wagons, we consider this price as good as $1.10 per cu. yd. f. o. b. cars on a railway siding the same distance from the road as is the crusher. The difference in cost between the stone on the car or bins of crusher and the finished road will always be large at best, and some of the items cannot be much further reduced in cost.

As the total cost from the crusher bin to the finished road, including compacting, ranges from nearly 50 cts. to

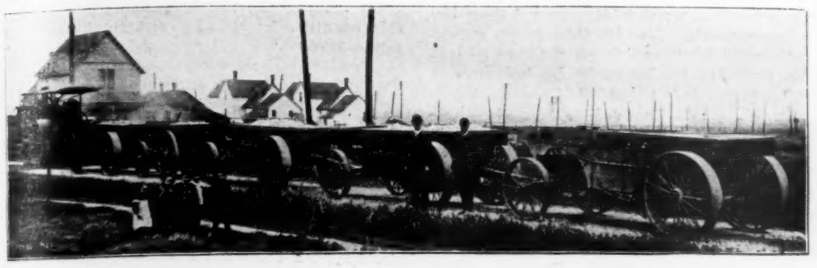


FIG. 1. STEAM ROLLER HAULING STONE DISTRIBUTING WAGONS.
Port Huron Engine & Thresher Co., Port Huron, Mich.

Fig. 2. Distributing Stone for New Road.

During the operation of the grader stakes were set parallel to the center line, and 11 ft. apart in cross-section, thus placing them 1 ft. outside of the central 9-ft. strip and on each side. This will be found a great convenience in holding the grader to line and the stakes will not be destroyed till the grading is completed and the rolling begins.

The edges of the bed were afterwards trimmed to line with shovels and the crown corrected wherever it was needed. During the hand trimming, the roller was passed back and forth over the subgrade and the trimming process continued till a well-shaped and well-compacted subgrade was produced.

The surveys for Dove St. were reduced to a minimum. Recently platted lots defined the side lines so that only a tape line and some pickets were needed to mark out the proposed bed. The land was very level, so that the only instrument work done was to set grade stakes for trimming the bottom of the ditches. About 700 ft. of this street, however, was broken up and newly "piked," and a very good grade made, thoroughly harrowed and rolled down with steam roller.

APPLYING THE STONE.—I will now confine myself to 24th St., the only difference being that Dove St. consists entirely of crushed cobble stones with limestone binder, while 24th St. has a lower course of quarry limestone and a top course of crushed cobble stones, all bound in with screenings from crushed cobble stones, so as to avoid dust as much as possible.

The bottom course of 24th St., to a depth of 0.36 ft. before compacting, was made of crushed limestone from Bay Port quarries. This was delivered to the street from the cars, partly with spreading wagons and engines, at a cost (as shown by the table) of a little more than 45 cts. per yard. This cost includes spreading, but not rolling. The stone was rather fine, in fact much of it too fine, and no binder was used in this course. It was rolled so as to compact as much as possible before the top course was applied.

The top course was of crushed cobble stones and one of the objects of this paper is to show that, even where stone must be freighted to the road, it is possible to crush them at a cost that will make country roads possible, and even bring this desirable class of road material

TABLE I. 24TH ST.

Summary of cost of macadamizing 24th St., 9 ft. wide, including the intersection of Griswold and 24th Sts., and the extras at intersections of private drives:

Grading	$46.96
Delivering 326.3 cu. yds. Bay Port stone at 45 cts., part with engine and spreading wagons, and part with teams	148.10
Delivering 328.5 cu. yds. crushed cobble stone at 54.86 cts., nearly all with spreading wagons and roller, including sprinkling and rolling	180.20
28.5 cu. yds. crushed cobble stone at $1.644 per cu. yd.	540.05
328.3 cu. yds. Bay Port stone at $1.53 per yd.	499.24
9.25 cu. yds. Bay Port screenings to redress road	13.30
Engineering	57.05
Total	$1,484.90

Note.—The work covered by the above cost is equivalent to 2,900 ft. of road 9 ft. wide, costing $0.513 per ft., or at a rate of $2,703.36 per mile. The total depth is 8.12 ins.; coarse stone is 6.01 ins. deep; binder is 2.11 ins. deep; 160 cu. yds. of binder was used, equal to 33⅓% of the coarse stone.

crushed stone, or 5.7 cu. yds. per cord, the stone being measured in three separate grades as it came from the crusher. The crushing cost in the second column is unduly large, owing to the fact that four bad breaks to the crusher occurred, causing a considerable loss of time. On three separate days the crusher only ran three hours per day, on two days only five hours per day, on two other days five and seven hours each per day, and on one other day eight hours, but full rental is allowed for the crusher on all of the above-mentioned days except one.

In July and August, our labor cost of crushing was but 25 cts. per cu. yd., while in October and November it reached as high as 35 cts., the latter being due to a very unfortunate series of break downs. (We do not build a crusher.) There were some breaks in the summer, but no doubt that may be considered a normal run as some breaks are unavoidable. The total crushing cost according to these figures, including rental of machinery, is rather high, yet one can see that crushed cobble stones, costing $6 per cord at the crusher, may be used and in our case not cost much more than crushed limestone from the quarries. In making comparison, one must remember that stone in the crusher bins can be loaded into wagons for 6 or 7 cts. per cu. yd. less than the cost of shovelling from the cars.

THEORETICAL COST.—As a good-sized rental figures into the above cost, I can see no reason why the following is not a fair method of figuring, for a contractor who owns the machinery. We will assume that a suitable crushing outfit of the same capacity as the one used in this trial can be bought for $1,500. We then have interest on $1,500 for one year at 6%—$90. The machinery should last ten years, making depreciation per year 10%, or $150; giving total machinery cost per year $240. Allowing that 100 days is an average year's work, we have a depreciation per running day of $2.40.

From the crushing tables we learn that the average crushing rate per hour for all the stone crushed was 6.28 cu. yds. We will call it 6 yds., and 60 yds. a day's crushing, thus making the cost per yard for interest and depreciation of machinery, 4 cts.

Referring to the table for July and August we have, as labor cost, including fuel, oil and repairs, 25 cts. per yd. To arrive at a suitable average material cost we will assume that cobble stones can be delivered at the crusher for $5 per cord. In a run of 9½ cords, the crushed stone per cord of cobbles amounted to 5.7 cu. yds., or an increase in bulk of 20%. The stone was measured in three grades, viz., as screenings, 1½-in. and 2½-in. stone. All stones that passed over the 2½-in. section of the screen were returned to the crusher by a carrier. Each cubic yard of

TABLE II. DOVE ST.

Summary of cost of ¼ mile of road on Dove St., October and November, 1901:

Grading and turnpiking	$54.45
192.5 cu. yds. crushed stone at $1.586, in wagons at crusher	305.24
58.7 cu. yds. screenings at $1.37, f. o. b. cars	30.42
Delivering crushed cobble stone with roller and spreading wagons, including sprinkling and rolling	141.98
Delivering binder with teams and spreading on street	31.49
Engineering	13.02
Total	$626.60

Note.—The above road is 9 ft. wide; stone and binder, 6.85 ins. deep; hard stone (cobble), 5.35 ins. deep; binder (Bay Port), 1.5 ins. deep; binder equals 28% of coarse stone. Cost per mile, $2,506.40.

over 70 cts. per cu. yd., a considerable percentage of which is due to spreading, watering and rolling, a saving should be effected along all of these lines. We are seeking to reduce the hauling and spreading charge by using the roller as a traction engine in place of horses (Fig. 1), and large wagons that spread the stone to any desired depth. We have reduced the rolling charge by delivering the stone with the roller and broad-tired wagons (Figs. 1 and 2), but the sprinkling charge has not been reduced. Wet weather can often be taken advantage of in country road building, and as much rolling as possible done when the weather is most favorable.

On Oct. 22, 79 yds. of stone were crushed and 76 yds. of this was delivered to the street, a distance of ¾ mile from crusher, with one roller and five wagons. We will suppose that a roller and five wagons is required for an outfit at a cost of $2,500. The interest on $2,500 at 6%, $150; depreciation at 10%, $250; total machinery cost per year, $400.

Again, taking 100 days as the working season, we have working cost at $4 per day, $4; labor cost per day for engineer, $2; helper on train, $1.50; fuel and incidentals, $2; total cost per day, $9.50.

Allowing that 76 yds. can be delivered per day, we have here a total cost of 13 cts. per yd. for hauling and spreading. The man who dumps the wagons can keep the street well trimmed at all times. To deliver the same with teams would require five teams at $3.50, or $17.50; also two men on road to help dump and spread at $1.50, $3; making a total per day of $20.50, or 27 cts. per cu. yd. to spread on road by common methods. Just what percentage of rolling can be credited to this method of hauling and applying the material to the road is not determined, but it is no small help toward the final consolidation of the road.

As supplementing the above paper, Mr. Rogers writes us that he noted the cost of macadam roads given in Engineering News of Jan. 9, and has computed from the figures per sq. yd. the cost per cu. yd., for better comparison with the figures given in his paper. He considers that these figures, given below, make a very favorable showing for his method of constructing roads.

Cost of Macadamizing Street by Day Work at Hudson, N. Y.; 4,228 sq. yds.; 6 ins. deep after compacting.

	Cts. per sq. yd.
Hauling 1½ miles from crusher	9.75
Cost of stone crushed	12.75
Cobble gutters, 24 ins. wide	5.07
Sprinkling	0.28
Rolling	3.27
Spreading stone	2.58
Excavating and grading subgrade	8.05
Total per sq. yd.	41.75

The same, reduced to cost per cu. yd., allowing 25% for compacting, or 4.5 sq. yds. for each cu. yd:

		Cts. per cu. yd.
Hauling 1½ miles		43.87
Spreading		11.61
Total		55.48
Sprinkling	1.26	
Rolling	14.71	
		15.97
Grand total per cu. yd.		71.45

ENGINEERING NEWS
AND
AMERICAN RAILWAY JOURNAL.

Entered at the New York Post-Office as Second-Class Matter.
Published every Thursday
at St. Paul Building, 220 Broadway, New York, by
THE ENGINEERING NEWS PUBLISHING COMPANY

GEO. H. FROST, - - - - - - - - - PRESIDENT.
D. McN. STAUFFER, - - - - - - - VICE-PRESIDENT.
CHARLES WHITING BAKER, SECRETARY AND MANAGING EDITOR.
F. P. BURT, - - - TREASURER AND BUSINESS MANAGER.

WM. KENT, E. E. R. TRATMAN, M. N. BAKER, CHAS. S. HILL, } ASSOCIATE EDITORS.

A. B. GILBERT, - - - - - - - ASSISTANT MANAGER.

CHAS. W. REINHARDT, - - - - - CHIEF DRAFTSMAN.

ALFRED E. KORNFELD, New York,
M. C. ROBBINS, Chicago,
S. B. READ, Boston. } ADVERTISING REPRESENTATIVES.

PUBLICATION OFFICE, 220 BROADWAY, NEW YORK.
CHICAGO OFFICE, 1636 MONADNOCK BLOCK.
BOSTON OFFICE, 170 SUMMER ST.
CLEVELAND OFFICE, OSBORN BUILDING.

FOREIGN AGENTS.

C. MITCHELL & Co, Snow Hill, Holborn Viaduct, LONDON.
RUDOLF MOSSE, BERLIN and HAMBURG, GERMANY.
JOHN F. JONES, & CIE. 31 Rue de Faubourg Montmartre, PARIS.

SUBSCRIPTION RATES: United States, Canada and Mexico, One Year, $5.00; *6 months,* $2.50; *2 months,* $1.00. *To all other countries in the Postal Union: Regular Edition, One Year,* $7.00 (31 *shillings*); *Thin Paper Edition, One Year,* $6.31 (26 *shillings*). *SINGLE COPIES of any number in current Volume,* 15 *cents.*

In requesting change of mailing address, state BOTH old and new address; notice of change should reach us by Tuesday to be effective for the issue of the current week. The number on the address label of each paper indicates when subscription expires, the last figure indicating the year and the one or two preceding figures the week of that year; for instance, the number 322 *means that subscription is paid to the* 32d *week (that is the issue of Aug.* 7) *of the year* 1902; *the change of these figures is the only receipt, unless one is sent by special request.*

ADVERTISING RATES: 20 *cents a line. "Want" and "For Sale" notices, special rates, see page XXIV-XXIX. New copy for standing advertisements should be received one week in advance of publication; new advertisements, Monday morning. The pages containing "Want," "For Sale" and "Proposal" advertisements are held open until Wednesday noon.*

The Colombian Government's message, read at the meeting of the Panama Canal stockholders on Feb. 28, furnishes good ammunition to those who have been opposing the Panama route on the ground of possible legal complications in securing its control. The substance of the message was that the company would not be allowed to transfer its concession to another nation without first obtaining the assent of Colombia to a modification of those terms of the concession which forbid the transfer to any government.

This message may mean much or little; but the most probable interpretation is that Colombia proposes to exact a price from the Frenchmen for permitting the transfer of the Panama works to the United States. Unless this is the case, it is difficult to see any reason for sending the message at all. Colombia's legal right to exact whatever price it pleases from the company for the grant of this privilege cannot be doubted; and in the present disturbed condition of Colombian politics, it can readily be imagined that any opportunity to raise funds is not likely to be passed by. As the whole question of the acceptability of the Panama route hinges on securing an absolutely clear title both from Colombia and from the Panama company, any signs of a hitch in the negotiations between these two parties is of much importance.

On March 3 the Senate sub-committee which has been investigating the legal status of the Panama enterprise voted to report that the legal complications surrounding the Panama Company's offer are such that it should not be accepted by the United States. The four Senators taking this position are Morgan, Mitchell, Foster and Turner. Senator Kittridge reserved the right to present a minority report and Senator Pritchard, the remaining member of the committee, was absent.

A recently published criticism of the Nicaragua route is to the effect that its curvature will make it very difficult and dangerous of navigation compared with the Panama route. It is even said that vessels can only be got around the curves by the use of tugs fore and aft. We know of no facts in the operation of vessels in existing canals or narrow channels to justify such a criticism. The bottom width of the canal is 150 ft., as compared with 115 ft. at Suez. The depth is 35 ft., whereas it is less than 28 ft. at Suez, and when the side slopes are taken into account it will be seen that the ordinary freight steamer drawing, say, 18 to 24 ft., has really a much wider channel than 150 ft. to manoeuvre in. Besides this, on all curves of less than 12,000 ft. radius, on channels of less than 500 ft. width, the bottom width is increased by 1 ft. for each 200 ft. reduction of radius. Thus, on a curve of 5,000 ft. radius, the bottom width of the 150-ft. channel will be increased to 185 ft. Now, in such a channel, of 35 ft. depth, a ship drawing 24 ft. depth will not touch the side slopes of 2 on 3 in firm earth until she has passed 15 ft. to either side of the bottom of the canal prism. Thus, the actual width of the channel for a 24-ft.-draft vessel on a curve of 5,000 ft. radius, is 215 ft., or probably at least five times the beam of such a vessel.

Under these circumstances we see no particular danger attached to navigating the curves on the Nicaragua route, and their disadvantages appear to us to be fully allowed for by the commission's estimate of the time of passage through the canal. The really great disadvantage of the Nicaragua route as compared with Panama is its greater first cost and greater cost of maintenance. As a transportation route when completed, there is every reason to believe it would prove at least as advantageous to commerce as the Panama route.

The New York legislature has acted wisely in its passage of the bill permitting New York city to grant the Pennsylvania R. R. a franchise for its proposed tunnels under the North River and East River, and its terminals on Manhattan and Long Island.

In the debate on this bill, Senator Grady urged that it would be better policy for the city itself to build the tunnels, and lease them to the railway, thus retaining ultimate control. There may perhaps be some valid arguments in defence of the theory that a city should control in some manner the railway terminals within its borders, although this theory has been largely rendered obsolete by the disappearance of railway competition and the acceptance of monopoly as the normal relation of the railway to the public. In the case of the proposed tunnel entrance of the Pennsylvania to New York, however, it is better by far for the city that the railway should take the whole responsibility and risk of the work. There are a good many unsolved problems and experiments to be gone through with before trains will be run underneath the North River; and such works for which no precedent exists are far more likely to reach success in the hands of a private corporation than in the hands of a municipality. A multitude of opinions exist as to where the line should be drawn in what is currently termed "the municipal control of public utilities;" but thoughtful men are agreed that the field of experiment is one on which a municipality should not enter, unless circumstances make it imperative.

We have received two communications during the past week concerning the metric system, each of them from a distinguished engineer of international reputation. The writer of one of these letters says: "No reasoning man to-day disputes the superiority of the metric system to all other systems." The writer of the other says:

It will be seen that the philosophical superiority of the English system lies in the fact, that figures express realities of distance or dimension with a definiteness that in the metric system cannot be approached. This is the secret of its greater convenience for mechanical measurements.

The first writer, a well-known member of the Institution of Civil Engineers, urges that the universal use of the metric system should be made compulsory in the British colonies in South Africa. The opponent of the metric system, who is an honored member of the American Society of Mechanical Engineers, asks us to print his letter because "a bill is now before Congress and in danger of becoming a law which will make the use of the metric system compulsory in the United States."

It is unfortunate that both our correspondents do not unite political wisdom to their professional attainments. England's past blunders in the conduct of South African affairs would be as nothing compared with the burden she would undertake were she to try to compel the Boers and Kaffirs, from the Cape to Rhodesia, to buy and sell only in meters and kilograms and liters. As for Congress making the metric system compulsory in this country, let us stop and think what that would involve. Legal compulsion to be of any effect, must include a penalty for disobedience of the law. Does anyone suppose the leaders of the dominant party at Washington are so blind as to make it a punishable offense to use pounds or yards or quarts or acres in the ordinary transactions of life? The despotism of a Napoleon might force such an upheaval of long-established customs upon a people; but under a self-governing republic, we see no possibility of forcing the metric system into use any more rapidly than people choose to adopt it.

Our old friend, "The Southern Review of Commerce," whose methods were exposed in our issues of Dec. 14, 1899, and Nov. 8, 1900, appears to be still doing business at its old stand, according to letters recently received by us. Not only this, but it has two competitors in its own field, the "Southern Trade Record," of Cincinnati, whose journalistic methods were elucidated in our issue of Dec. 28, 1899, and "The United States Trade Reports," also of Cincinnati.

The method of operation of all these concerns is substantially the same. A highly flattering "trade write-up" of some manufacturer's productions is prepared and sent to him, with a letter stating that the "write-up" is shortly to be published in the journal named, and he is invited to purchase extra copies of the issue in which said write-up appears. While the "write-up" invariably states that it is an "unsolicited and impartial endorsement," prepared in response to the queries of a multitude of [mythical] subscribers, in the letter accompanying the copy, the manufacturer is requested to "add to or alter it as he thinks best." The paragraph of the letter which follows, however, indicates that the editor is lacking in a sense of humor. We quote it as follows:

This being our opinion, given, editorially, we, of course, do not charge for same in any way and the benefit you will receive from such a disinterested statement of facts, will repay you for your time in helping us in its preparation.

The "write-ups" themselves are such literary gems that we take space to quote from a few of them. The following is from one recently sent to the Westinghouse Machine Co., of Pittsburg, Pa., and forwarded to us: We quote "verbatim et literatim":

MOST RELIABLE JUNIOR ENGINES.

The policy of the Southern Review of Commerce to investigate and publish result, free of charge, any matter of business importance to inquiring patrons, brings many and varied requests for advice, which we deem a potent factor in building up our large circulation.

Possibly the tendency of the South toward obtaining the most modern machinery is responsible for the numerous inquiries lately received from manufacturers among our readers asking us to recommend the best junior engine; and that we might make a truthful and intelligent reply, we have just concluded one of our invariably careful and exhaustive investigations, through our special representatives in the principal cities, and after their full and detailed report, we do not hesitate to give our unqualified indorsement to the Westinghouse Junior Engine, built by Westinghouse Machine Co., Pittsburg, Pa.

As most of our readers are doubtless aware, the "Junior" engine is the trade name of one of the smaller sizes of engine made by the Westinghouse Co., and by no other firm whatever, a fact with which the expert editor, who assumes to pass judgment on everything under the sun, was manifestly unacquainted.

Here is another case where the editor of one of these journals—"the United States Trade Re-

ports," this time—made a bad slip. He sent a "write-up" to the B. F. Sturtevant Co., of Boston, from which we quote as follows:

The American dyer has attained a position of great prominence among the dyers of the world, and his productions are admitted by practical and expert judges to possess many points of superiority over those of foreign concerns. This is in a large measure due to the improved machinery which various manufacturers have placed on the market from time to time, and which embody all the best ideas of practical and scientific men, who have made the subject of dyeing a life study. Many inquiries on the subject of dyeing machines caused us to make an investigation of the products of the various concerns engaged in this line of manufacture. The result has convinced us that the best dyeing, drying, bleaching and finishing machinery is manufactured by the B. F. Sturtevant Co., Boston, Mass.

In their letter transmitting this production to us, the Sturtevant Co. comment on it as follows.

The absolute worthlessnes of such a publication is only too well displayed by their statement that their investigations have convinced them "that the best dyeing, drying, bleaching and finishing machinery is manufactured by the B. F. Sturtevant Co., of Boston, Mass." In point of fact, we do not manufacture dyeing, bleaching or finishing machinery, but are only interested to the extent of building apparatus for drying textile goods.

According to the letter head of the "United States Trade Reports," its editor is Geo. C. Carter, who, it appears from other letters in our possession, was in 1899 the editor of the "Southern Trade Record." Examination of the letters, sent with the "United States Trade Report" write-ups, shows that they are not even written, but are printed by the wholesale by some process in imitation of typewriting. The fact is of interest as indicating the extent to which these write-ups are being circulated.

Further comment on the character of these enterprises than the quotations above printed would be superfluous. The fraud involved is so evident on its face that the wonder is that reputable manufacturers can be victimized by it. That some are caught is evident from the mere fact that these publications continue to exist, for that bona-fide paying subscribers should be found for a journal of such character is, we need hardly say, quite unthinkable.

Apropos of our remarks last week concerning the proposed tunnel route for an Isthmian Canal, we commend to the consideration of the advocates of such a route the description in our present issue of the Aspen tunnel on the Union Pacific Ry. The difficulties experienced in holding this small single-track tunnel, and the enormous pressures to which the lining was subjected are an excellent illustration of the forces with which the engineer in charge of tunnel work frequently has to contend. That these difficulties increase very rapidly with the size of the tunnel is a fact so well known to engineers that we need only allude to it here.

SOME REFLECTIONS ON THE LUXEMBURG BRIDGE.

We gave considerable space in the last issue of Engineering News to an illustrated description of the large masonry arch bridge now being constructed at Luxemburg. This bridge is one of the most notable engineering works of modern times, and as such its design and construction are of great interest to engineers. It is probable, moreover, that many engineers will ask themselves whether in this age of steel such large and expensive viaducts in masonry are warranted by any advantages which they offer in the way of pleasure to the artistic mind, or in the more practical and material fields of durability, fitness and economy as a tool of transportation. The question is worth considering.

It is plain, we think, that considered merely as a tool of transportation, the typical steel viaduct, however ugly its outlines may be thought, is a more logical structure than the stupendous arch of costly masonry which we have illustrated. The Luxemburg arch, then, must seek its warrant for existing chiefly in the greater measure in which it satisfies the desires of educated men for beauty as well as utility in the structures which civilized society demands for its use and pleasure. If our foreign contemporaries report the matter correctly, it was solely because of the greater beauty of the stone arch that the Public Works Department of the Little Duchy of Luxemburg gave preference to it over structures of iron and steel. It is upon this feature then that the success or failure of the bridge must be judged.

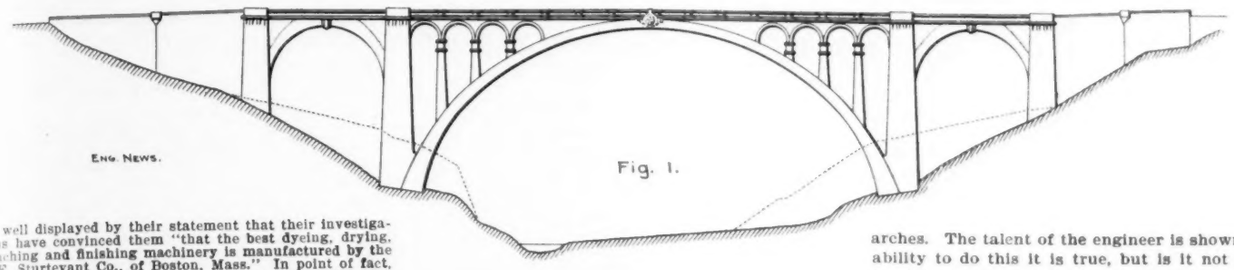


Fig. 1.

We may grant, we think, that the local conditions justified to an exceptional degree the choice of a masonry bridge. The city of Luxemburg is situated at the top of a rocky escarpment and still presents to the eye all the grim strength of masonry which at the beginning of the last century made it the strongest fortress in Europe with the exception possibly of Gibraltar. The city is a monument to the mason builder; it was especially fitting, therefore, that the great bridge by which the approach to the city is made should be a product of the mason's art. In granting this, however, we must guard against the mistake of assuming any general application of the conclusion. The surroundings at Luxemburg were exceptional and they demanded an exceptional structure to harmonize with them. A truly exceptional structure was designed and is being built, as may be readily seen by making a few comparisons.

The Luxemburg bridge has the longest arch span of masonry ever built. The arch which approaches nearest to it in span is that built over the River Adda near Trezzo, Italy, in 1350 and destroyed in 1416. From the ruins which remained in 1838, about 20 ft. of each abutment, the span has been determined to have been about 251 ft. The nearest in size to this medieval structure is the Cabin John Bridge at Washington, D. C., built in 1852-9. This arch has a clear span of 220 ft. Comparing merely their spans the Luxemburg arch is 26 ft. longer than the destroyed work of the Italian engineers at Trezzo, and is 57 ft. longer than the arch built by the United States army engineers at Washington. Engineers familiar with the principles of the arch and with the materials dealt with, will readily appreciate what this increased dimension involves and will cheerfully grant the praise due to the builders of the designer who has undertaken it. It is unfortunate that with this feeling there persists the somewhat ungenerous thought that the designer has given way to the Frenchman's love for producing a tour de force.

This brings us back to the original thought that there is something uncongruous in this age of steel, in straining the resources of engineering knowledge to wring from stone masonry its utmost possibilities as a structural material for arches. The talent of the engineer is shown in his ability to do this it is true, but is it not a more sensible, logical and legitimate exercise of talent to select for a structure the material most suitable to it than to adapt an intractable material at great toil and pains to that structure. We know that many engineers feel that it is and we believe that their feeling is not unworthy of consideration. The reason that this feeling is so seldom expressed is that it seems open to the charge that carried to its logical conclusion the theory advocates the cheapest structure which will do the work. This charge is quite unwarranted, for it requires all questions of beauty to be eliminated, and no engineer willingly consents to that even though his notions of what is truly beautiful are very crude. The incongruity to the structural engineer of stone arches of such great spans as have been mentioned does not rest on the fact that they are an excessively expensive tool of transportation; to him it seems founded on a far deeper reason though one which he can but vaguely define.

An illustration will do something to clarify matters. For example, up to a certain span a stone beam or lintel is a suitable structure for carrying weight and also appears suitable for the work. Beyond this span it appears to the eye unsuitable for the work it has to do, even though by skilful design, workmanship and adjustment of the load it safely does that work; the eye unconsciously demands a stronger appearing structure and is better satisfied with an arch ring, even though it is really no stronger. In exactly the same way the masonry arch ring at length reaches a span where to the trained eye an obvious strain is necessary to secure the design, workmanship and distribution of load which will permit the material used to meet the demands put upon it. At this point as in the case of the beam the substitution of another form of structure or of another and obviously stronger structural material seems called for. Why, then, not meet the demand frankly and substitute a steel arch ring for one of masonry? Would this not be an observance rather than a breach of the laws of aesthetics? These are questions which a number of engineers are asking, and to which they have received no very satisfactory answer. We confess that we see no sign of an answer in the Luxem-

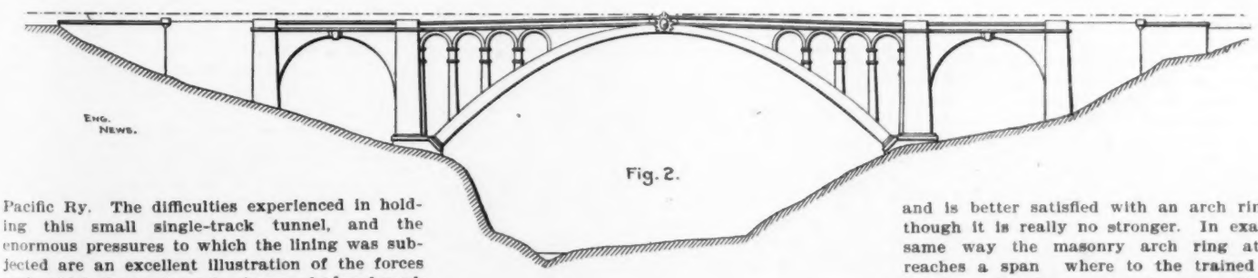


Fig. 2.

burg arch to which we will now refer more particularly.

As was indicated in a preceding paragraph the Luxemburg Bridge is essentially a tour de force of engineering skill. Is it successful? Structurally it is, without doubt, but artistically it is open to criticism. These are rather bold assertons, but we think it can be defended. When we study the bridge as shown by the elevation, on our inset last week, we must confess to a strong feeling of dissatisfaction with the treatment of what may be called the abutment portions of the main arch. The real springing lines of this arch, being buried beneath the surface of the ground, are invisible, so that much of the boldness of the arch span is lost to the eye. This in itself is regretable, but besides this fault, for which there is a reasonable excuse, the designer has, it seems to us, voluntarily confused the apparent dimensions of the visible portions of the arch by merging the lower segments of the arch ring into a sort of false abutment. The result of this is that the eye attempts at first sight to picture the arch ring as terminating at the top line of the false abutment or where the smooth cut arch ring stones end. This attempt is rendered abortive by a second glance which shows that the wall first thought to be solid abutment masonry, is really a screen, or spandrel, wall carried by the arch ring, which itself continues as a different class of masonry below its seeming ends and disappears into the ground with no visible skewback. The real structural conditions are of course readily inferred by the engineer, but they do not appear so plain to the layman. The question arises, then, whether some effort would not have been warranted in an endeavor to make the structure appear to be what it really is.

It will be remembered by some of our readers, that, in constructing the Cabin John arch, the rock on each side of the ends of the arch ring was cleared away for some distance to render visible the skewbacks, which would otherwise have been out of sight beneath the broken surface rock of the gorge. The thought that a similar procedure with the bridge illustrated would improve its looks suggests itself. If the earth were removed to bed rock as indicated in the accompanying sketch (Fig. 1) and the end construction altered as shown, the engineer could have made the magnificent full span of his arch visible and obvious to the most casual observer. Judging from the rather obscure half-tone views of the arch which are printed in "Le Genie Civil," to which we are indebted for the drawings shown on our two-page plate, this removal of the surface soil could have been accomplished at a very small outlay. Structurally the arch is just as bold in design and construction as it stands as it would be were the changes made which have been suggested, but to the eye it appears far less bold and monumental than it would were the changes made.

A preferable solution of the problem in some respects would have been to make the span of the arch what it seems to be as is indicated in the sketch, Fig. 2. In this sketch a parabolic arch ring has been substituted for the polycentric arch rings shown in the sketch, Fig. 1, and in the general elevation on the two-page plate. As will be noted the skewbacks are located at about the elevation where the arch ring as it is being built sinks into the ground. The visible span in both designs is, therefore, the same, but the design shown by the sketch Fig. 2 has the superior merits that it gives the same visible span by means of a ring which is really 20 ft. less in span and which has visible skewbacks and foundations. It is not pretended that these suggested designs have been carefully worked out, but they present plainly if crudely the points we wish to make.

Turning now to the construction of the Luxemburg arch as it is being built, there is one feature of the work which deserves further mention than was given it in the descriptive article published last week. It was an original and truely noteworthy conception to reduce the cost and difficulty of construction by building two parallel arch ribs which serve as supports to a thin roadway platform spanning the space between them. Expressed in definite terms it reduced the volume of masonry one-third, and it reduced the weight to be carried by the arch center about two-thirds.

LETTERS TO THE EDITOR.

The Rapid Extension of Concrete Steel Construction.

Sir: Any American engineer traveling abroad will be surprised at the amount and character of work executed and being executed in reinforced concrete in Europe. The application of this method is not localized, but is seen applied in all countries of the Continent and in England. Not only this, but its use has been sanctioned by some of the best-known engineers as well as officially by the various governments of Europe. The length of time during which this method of construction has been used leaves no doubt as to its efficiency, and the fact that Prof. Dr. W. Ritter, of the Zurich Polytechnicum, is lecturing thereon has given it a standing which American engineers must, sooner or later, recognize.

You are to be complimented for publishing the able paper of Professor Hatt in your last number, and I sincerely trust that you will find it possible to keep your readers informed upon this subject by similar publications from time to time. Yours truly,

J. O. Ellinger.

1707 Park Ave., Baltimore, Md., March 1, 1902.

Non-Continuous Swing Spans.

Sir: It is probable that every old bridge engineer will, as does the writer, look back on his efforts to solve the problem of a non-continuous draw bridge in some easy way. Fully twenty years ago I got up three different designs, one exactly similar to the one you publish in your issue of Feb. 27. The strain sheets are all easy, but when the question of operation was taken up, they were all laid away in the scrap heap. I have read your article carefully in hopes the real difficulty had been solved, but it is not even hinted at.

That very useful handmaid of the engineer, friction, *is* also an awful obstacle when motion is needed. On the pulling bars at the top of the design, the author gives 171,500 lbs. on a 4-in. pin, and on the hinge below a still larger reaction, due to the above pull and the dead load of one truss.

If the pressure on these journals was limited to 1,200 instead of 12,000 lbs. per sq. in. (and I should prefer for a slow-moving reciprocating journal to limit it to 800 lbs.), the size and proportions of the needed journals may be determined.

When this question of the journal is solved in a simple and practical way, the proposed design may be made to work. Old Fogy.

New York, Feb. 28, 1902.

Still Further Discussion of the Upper Tallassee Dam

Sir: I have read Mr. Temple's letter to the Engineering News, dated Feb. 13, 1902.

The freshet of Dec. 29, at the time our contractors met with an accident, was the greatest since the establishment of the gaging station on the Tallapoosa River. Had the dam been finished and the big coffer dam, with its height of 5 ft. over the crest of the main dam, been removed, certainly a greater length of spillway would have been had and naturally less height of water over the dam. Notwithstanding this, and assuming a depth of 10 ft. of water over the rollway, 150 lbs. per cu. ft. for masonry, and the section shown by Mr. Temple, the resultant falls well within the middle third.

An error of considerable importance in Mr. Temple's computation is the unit weight of masonry assumed by him, namely, 150 lbs. per cu. ft. As a matter of fact the rock used in this dam and the method of construction was such that the weight exceeds 160 lbs. per cu. ft.

Mr. Temple says:

While the S. Morgan Smith Co. furnished the turbines for the Montgomery plant, they were not responsible for any other part of the work. Had they been responsible for its design and construction, I am free to say that both would have been materially different.

Mr. S. Fahs Smith, of the S. Morgan Smith Co., is a director of the International Hydraulic Co., and quoting from a letter received from them, dated York, Pa., Feb. 15, 1902, Messrs. Smith state:

This company is in no wise interested in the controversy between the International Hydraulic Co. and our Mr. J. C. Temple. Mr. Temple has no authority to use our name in any of his articles. We are not interested in engineering work. The building of dams, power houses, etc., is out of our line and we do not want to be thrown into the controversy.

It is a pertinent fact that we have been acting as consulting engineers for the S. Morgan Smith Co. in connection with a proposed water power development on the Chattahoochee River, in Georgia, in which they are financially interested.

Mr. Temple further states that the dam in question went out two days after his criticism. This is certainly news to us, for, as already represented in the Engineering News, our contractors, during the big freshet of Dec. 29, last, met with an accident when the closure under construction and its big coffer dam were carried out. No doubt this is what Mr. Temple refers to. Yours truly,

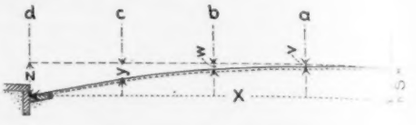
The International Hydraulic Company.

40 Wall St., New York, Feb. 19, 1902.

The Proper Crown for Macadamized Streets.

Sir: I was very much interested in reading an article on macadam roads by Mr. Halbert Powers Gillette, published in your issue of Sept. 19, 1901. The part of the article that appealed to me was the portion relating to sharp crowns. I will agree with Mr. Gillette in regard to sharp crowns for macadam streets in towns and cities. I would make one qualification, however; the crown of the pavement should depend in a great measure on the volume of traffic. Streets of light traffic should be given sharp crowns, which should be lessened as the traffic increases but should never be less than ½-in. to 1 ft.

After several years' experience with macadam streets in Hudson, N. Y., I have adopted the following method of distributing the crown.



Let

s = total crown according to judgment based on the volume of traffic;
x = one-half width of roadway;
a = a point $^1/_4$ x distant from center of the roadway;
b = a point $^2/_4$ x distant from center of the roadway;
c = a point $^3/_4$ x distant from center of the roadway;
d = a point $^4/_4$ x distant from center of the roadway.

A string is stretched from the finished surface at the center of the roadway to the curb, the curb end being raised until the string is level. Now to find the distances to the finished roadway from the string at the points, a, b, c and d, we proceed as follows:

$v = (^1/_4)^2 s = {}^1/_{16} s$; $\quad y = (^3/_4)^2 s = {}^9/_{16} s$;
$w = (^2/_4)^2 s = {}^4/_{16} s$; $\quad z = (^4/_4)^2 s = s$.

This gives the surface a gentle slope which increases as it approaches the gutter. Such a surface allows the rainfall to readily run off to the gutters and at the same time does not force the traffic to the center of the roadway as happens with a street having an even fall per foot from the center to the curb line.

My experience has been to give a roadway of 30 ft. a crown of from 9 ins. to 15 ins., according to the amount of traffic. A good rule to follow is to allow a crown of 1 in. per ft. for streets of light or medium traffic. The flatter the crown, the more the care to be taken in forming the section and compacting the material and foundation by rolling.

We have had the best of success with a crown of 15 ins. on the ordinary city street. We find that the pavement lasts longer, keeps cleaner and gives a much neater appearance to the street with a sharp crown. After a heavy rain the pavement is washed clean and all refuse is easily collected and removed from the gutters and catch-basins.

With our streets this increased crown cheapens the construction as the new macadam can often be spread over the old road surface without any excavation in the center portions of the highway. Yours truly,

H. K. Bishop,
Superintendent of Public Works.

Hudson, N. Y., Feb. 25, 1902.

Examples of High Earth Dams.

Sir: In regard to the maximum height of earth dams, research would probably reveal a number of examples having effective heights greater than 70 ft. The Druid Lake dam, of over 95 ft. effective height, has already been described in your columns. Several high Indian dams are described in the 12th Annual Report of the U. S. Geological Survey, in a contributed paper, "Irrigation in India," by Herbert M. Wilson, M. Am. Soc. C. E. Brief descriptions are quoted below:

An example of one of these old tanks thus abandoned, but capable of restoration, is the Mudduk Masur tank, believed to have been constructed about four centuries ago. . . . . The length of the main dam is 1,650 ft. The inside slope of 1 on 2½, in some parts 1 on 3, was revetted with large stones up to 1 cu. yd. in bulk. The main dam is from 945 to 1,100 ft. wide at the base and is now from 91 to 108 ft. high. There was a sluice under the dam at the east end above the level of the ground. The material of which the dam is constructed is a strong red earth with a considerable mixture of gravel, and was taken from the sides of a hill in the neighborhood. . . . The west supplemental dam, the breaching of which destroyed the tank, was of similar construction to the others, and its base was 60 to 70 ft. above the bed of the tank. There was no trace of any waste weir, and it is probable that the want of this was the cause of the ruin of the tank. From the heights of the dams and the levels of the sluices it is probable that the depth of the tank was 90 to 95 ft., and at that level its area would have been 40 square miles and its contents about 870,000 acre-feet of water.

No mention is made of any wall of puddle or other material, and such construction probably was not known at the time these dams were built.

Several long earth tank dams built by the Indian Government are mentioned, among them three with heights of 58, 72 and 77 ft., and top widths of from 6 to 8 ft. While not remarkable for their heights, at least some of them had no puddle walls, except in the earth below the base of dam, and side slopes of 1 on 1½ above high water

level, with slopes below that of 1 on 2 for the outer slope and 1 on 3 for the inner.

In the 18th Annual Report of the U. S. Geological Survey, 1896-97, Part IV., in a report contributed by James D. Schuyler, M. Am. Soc. C. E., entitled "Reservoirs for Irrigation," somewhat meager descriptions are given of two very high earth dams forming storage reservoirs for a part of the water supply of Oakland, Cal.

The Temescal dam was built in 1868. It is 105 ft. high, 18 ft. wide on top, with side slopes of 2½ to 1, both above and below, which have been greatly increased and flattened by the material sluiced in from year to year subsequently.

The area of the reservoir is 18.5 acres and its capacity 188,000,000 gallons.

A very small scale sketch, which does not agree well with the dimensions stated, shows the water 5 ft. or 10 ft. below the top and a core wall of masonry or puddle with battered sides extending from the top of the dam many feet into the underlying earth. The dam was largely built by the hydraulic process. The last-named report also says:

The San Leandro dam was built in 1874-75, and has a height of 120 ft. above the stream bed. It is located 9.5 miles east from Oakland (California), 1½ miles above the village of San Leandro, at an elevation of 115 ft. above tide. The total volume of the dam is 542,700 cu. yds., of which 160,000 yards were deposited by the hydraulic process.

The reservoir covers 335 acres and has a maximum capacity of 4,323,446,000 gallons.

The area of the watershed tributary to the reservoir is 70 square miles, from which the run off is generally in excess of the storage capacity, and considerable difficulty was experienced in disposing of the surplus without washing away the dam, until a waste tunnel, 1,100 ft. long, with a capacity of 2,000 sec.-ft., discharging into the stream half a mile below the dam, was opened in 1888.

From some very small scale sketches this dam seems to be about 60 ft. wide on top and to have this 60 ft. width built of either selected materials or puddle. This selected material has its sides vertical and its base is begun in a trench 5 to 10 ft. below the original earth surface. The top of the dam is 110 ft. above the up-stream toe. The intersection of the lower slope with the original surface is 120 ft. below the top of dam, while its intersection with the horizontal filled surface is 100 ft. below. The upper slope is uniform and 3 to 1, while the lower slope is irregular and 4 to 1. The length of crest is 450 ft. No information is given from which the height of top of bank above the water can be ascertained. Except where quoted, the dimensions are scaled and approximate only.

The San Leandro dam is an example of a very high earth dam which was successful, but it also seems an example of almost criminal imprudence. Its inadequate spillway in combination with its earth construction, its great volume of stored water, and its location only 1½ miles above a village and 9½ miles above a large city, at a considerably higher elevation, all combine to make the risks taken in the case of the famous Bear Valley dam look very small in comparison.

Among "projected" California dams, Mr. Schuyler mentions two earth dams, each of 130 ft. height, and one of 155 ft. height, all to be built by the hydraulic process. I do not know whether they have since been built.

In the editorial "Concerning the Design of Earth Dams" in your issue of Feb. 20, you say: "Water percolates through even the best masonry, and such rubble masonry as is laid in core walls is bound to be far from water-tight." Water does percolate through even the best masonry, but "such rubble masonry as is laid in core walls" is (at least in the dams in the Croton drainage area), the very best quality of rubble masonry that can be made. I can say this with a full knowledge of the facts, having been for a time engineer for the contractors on one dam of the New Croton system and having later built two more of these dams as superintendent for the contractors.

You also assume that in carrying a masonry core wall to rock it is necessary to excavate a deep open pit with broad side slopes. I have never known of an instance of this kind of construction, the usual method being to reach the rock or hardpan by means of a sheeted trench having a width, out to out of sheeting, about 6 ft. greater than the bottom width of the core wall.

I think it is safe to say that the fears now current as to the entire safety of the Croton dams, or as to any of their earth portions being too high for safety, are not shared by those engineers who have the most thorough knowledge of these structures. The only dam on the watershed which has caused any anxiety is a masonry, and not an earth dam. This is the Boyd's Corner dam, built in 1867-70. It is described by J. J. R. Croes, Past Pres. Am. Soc. C. E., in the Transactions of the Society for 1874. Mr. Croes was, I believe, the resident engineer. The profile of this dam is poor and the dam is, besides, far from water-tight. I have frequently seen water squirting from its down-stream face with the reservoir only partially full. Its known condition modified greatly the design of two dams a few miles below. It is located in a wild region, only a short distance above another reservoir, and it is not probable that its failure would cause either loss of life or much destruction of property.

Edwin Duryea, Jr., M. Am. Soc. C. E.

No. 1 Broadway, New York city, Feb. 22, 1902.

Concerning Railway Location.

Sir: In your issue of Nov. 29, 1900, you published my communication on the subject of "Poorly Located Railways," and while I expected more criticism than I received. I expected it from a somewhat different direction than that from which it came.

I note your own criticism, to the effect that a large proportion of the railroad construction of the present day is done by old-established companies, and in a systematic manner, but I claim that this is true only to a very limited extent.

As a rule, the old-established railroad companies have an engineering force on each division, consisting of one man with probably one or two helpers, whose business it is to stake out an occasional turnout, lay out an arch culvert or some other "permanent construction" (on what is probably the "wrong location"); and on none of which is he called upon to exercise his own judgment, as that is all decided in the office by "a higher power."

If it should be decided that the business of the road warranted the building of a branch line, the aforesaid "power" will address a very lengthy communication to his engineer, ordering him to at once proceed to "a point," and from there make the location to "X" by the way of "Brown's Saw Mill;" and that the location must be made in the shortest possible time, as the contract has already been let, and the contractors will be moving on the work, and the trains must be running by the "time snow flies."

The chances are that this man has never had any experience on location outside of the college campus, but he is willing and feels the importance of his position and will do the very best he can. The location will be made, however, i. e., a line of stakes will be properly driven, the tangents connected by "spiral curves," and some fine blue prints made of both map and profile. The branch line will be completed and everybody happy; but the chances are that the whole expenditure has been a mistake, and that the first mistake was made by "the power" in designating the starting point; that the line should not have been located by way of "Brown's Saw Mill," but if it was necessary to reach "Brown's Saw Mill" that it should have been done by a spur from the branch line. I know that to a great many of your readers this will seem "far fetched," but I can count similar instances, as many as I have fingers on both hands.

In regard to the rules laid down by Mr. McHenry, Chief Engineer of the Northern Pacific R. R., they are a step in the right direction. But in this instance it is another case of "locking the stable after the horse is gone," so far as the original location of the main line of the Northern Pacific is concerned. I think Mr. McHenry himself will bear me out in my assertion, that that line has at least a thousand miles of bad location, and that a vast sum of money has and is being expended in the endeavor to rectify some of the worst mistakes.

One of my critics calls my attention to a change made in the location of the Atchison, Topeka & Santa Fe R. R. at some point in Kansas, to accommodate an increased tonnage, etc., and from his explanation of it I am not quite certain now that the line has been improved. The same party, I think it was, called my attention to the changes which had been made in the road running from Lordsburg, on the Southern Pacific, northwesterly, and, in fact, I remember seeing quite an extended description of the improvements in your journal. He attempts to defend the location and construction of the original line by saying "that it had answered all the purposes." The same thing might be said of the "bull teams" which used to haul the copper matte from Clifton, Arizona, to the Missouri River. I have never been over this line, but I remember very well when it was constructed, and I never heard a railway man who had been over it mention it without accompanying his remarks with a wink.

I stand on my original proposition, and that is that in nearly every instance where improvements have to be made in after years, and large sums of money must be expended in order to make the improvement, it is the result of absolute ignorance on the part of somebody in making the original location.

My experience and observation are, that if the young engineer starts out in life in a country where heavy curvature is the rule, he will not hesitate to use it, on a very slight provocation. Only a few years ago I had occasion to ride over one of the prominent railways of Mexico, which runs over a high, rolling and open country, and is mostly made up of long tangents; but on several hundred miles of the line I noticed that the tangents were almost invariably connected by heavy curves, and no reason could be seen for these curves. I made up my mind that it must be one of the cases where the engineer's early training and experience were gained in a country where such curves were necessary. I investigated and found that I was right in my conclusion.

One of the prominent railways between the Mississippi and Missouri Rivers had the misfortune to have a chief engineer who was a "crank" on the subject of light curvature; and in making his location on either a divide between waterways or in following the valleys, he could not find decent room for his curves, and the consequence was that in almost every instance he was thrown into an unnecessary expenditure of money to make deep excavations and heavy embankments, with a corresponding badly "chopped up" grade line. This was costly, but the road "has answered the purpose," and, strange to say, the property continues to pay a regular dividend.

During my early experiences, I was a member of an engineer corps under the direction of this same chief engineer. The party was in charge of an engineer of considerable experience, and his instructions were to proceed to make a location over ground on which there had been no preliminary survey, but he was given a maximum for both grade and curvature. The maximum curvature I remember was 3°. We were following a valley, and soon we came to a point where the river ran close to the bluffs. The chief of party finally decided that the best location he could make here was a 3° 30′ curve, and it was put in. The chief engineer in a few days received the information, and he was soon on the ground with "his back hair down," but after spending three or four days, he concluded to "let the matter rest for the present."

I do not claim that these results are the fault of the engineers, as I endeavored to make clear in my former communication; but I do claim that it is the fault of the management of these great properties. I also claim that there is only one department in the operation of railways which comes at all near perfection, and that is the mechanical or motive power department—I might possibly include the auditing department, but the perfect auditor seems to be one who is able to keep his accounts in such manner that no one except himself can tell anything about them. The principal reason for the perfection of the mechanical department is that the results of its work are in full sight, and are continually being compared by days, months and years.

Other departments have some of these advantages, but not to the same extent. But the efforts and desires of the poor civil engineer are not appreciated, for the simple reason that the management does not know whether his work is good or bad; and the engineer has no way of making comparisons. The management does not know that when he located the branch line from "a point" to "X" that he avoided an expense of a 1,000-ft. tunnel, or two expensive crossings of the river; or that when he was burning the midnight oil in a leaky tent, he had solved the problem of selecting a route which enabled him to reduce the maximum grade 25%, as well as to throw out 500° of curvature. All of this the management will never know, and would probably not understand if it were explained. On the other hand, if the engineer had built the tunnel, and spanned the two crossings of the river by immense steel structures, at a large expenditure of money, the world at large would have pronounced him one of the coming engineers, and it is more than likely that some one would have given a dinner in his honor.

How many traffic managers are there who could tell you, within 25%, the actual cost of handling freight over an individual road; or could tell, within 50%, the difference between the cost of handling it over the division with heavy grades and the one with light grades? The traffic manager would probably turn to the last annual report of the Interstate Commerce Commission, and give you the average cost per ton per mile of all the roads in the United States.

The time will come when the real cause for financial wrecks in the railway world will be known; but not until more men study this great question of railway transportation.

Do not understand me as wishing to convey the idea that this state of things is universal. There are persons connected with the management of railways who understand the condition of affairs, but usually they are in a minority and are powerless to act. A student of transportation understands that the first place for establishing economy is in the original location of the road. If he had concluded that "X" should be reached by a branch line, he would have called in his engineer and instructed him to ascertain "what point" would be the proper one from which the line should start, and what would be the proper way for reaching "Brown's Saw Mill." And last but not least, he would know whether his engineer was capable of giving him the proper answer. He would know, when the work was all complete, that it was by good judgment and careful work that his engineer had succeeded in avoiding the tunnel and two expensive river crossings, and had been able to save 25% on the maximum grade.

Yours truly,

Phoenix, Ariz., Jan. 21, 1902. P. F. Barr.

Notes and Queries.

Concerning the inquiry of A. L. H. in our issue of Feb 20 as to whether a degree of longitude had ever been measured south of the equator, it appears that we misunderstood his question. The arcs in Peru and at the Cape whose measurement we instanced were arcs of a meridian; and it is an arc of a parallel to which A. L. H. referred. If such an arc has ever been measured in the southern hemisphere will some reader inform us.

W. N. P., Philadelphia, Pa., writes:

Where can data be found in reference to the thickness

of circular retaining walls? The wall proposed is 120 ft. in diameter and some 15 ft. high.

We assume that the wall is to sustain a pressure inward, in which case the stresses in it would be similar to those in an arched dam, such as the Bear Valley dam in California. A mathematical discussion of such dams will be found in Prof. Dubois' new treatise on Mechanics. A description of the Bear Valley dam was given in our issues of Nov. 23 and 30, 1889.

REPORT ON THE ST. LOUIS WATER SUPPLY BY AN EXPERT COMMISSION.

Abstracted by Robt. E. McMath,* M. Am. Soc. C. E.

On July 25, 1901, Messrs. Benezette Williams,[1] Geo. Y. Wisner,[2] M. Am. Soc. C. E., and Allen Hazen,[3] M. Am. Soc. C. E., were appointed by the city of St. Louis, Mo., as a commission of expert hydraulic engineers to "carefully examine the present water plant of the city and thoroughly investigate and submit a report, with estimate and recommendations as to the most feasible manner of providing the city with an adequate supply, both present and prospective, of clear, wholesome water." The commission submitted, on Jan. 27, 1902, a majority report by Messrs. Williams and Wisner and a minority report by Mr. Hazen.

The commission studied two general plans of supply. (1) For an extension of the present system of taking water from the Mississippi River by pumping to sedimentation, coagulating and filtering works and re-pumping the clear water to the distributing system. (2) A new source of supply, that of the drainage area of the Upper Meramec River, delivered by gravity into the distribution system. The majority report favors a new gravity supply; the minority the old supply, filtered.

THE MAJORITY REPORT.

PRESENT WORKS.—The present works consist of three stations: (1) Chain of Rocks, where six pumps, with a combined capacity of 160,000,000 gallons, lift water to six settling basins, each 600 × 400 ft. in plan, and having a combined (actual or cubical) capacity of 174,000,000 gallons. (2) Baden, where there are six high-service pumps, with a combined capacity of 80,000,000 gallons. (3) Bissell's Point, where, including pumps now under construction, six other high-service pumps, with a combined capacity of 114,000,000 gallons, lift water from the original settling basins, now used for storage, which basins have a combined capacity of 90,000,000 to 100,000,000 gallons.

A masonry conduit 13 ft. in diameter, with a capacity placed by the majority of the commission at 130,000,000 gallons a day, extends from Chain of Rocks to the Baden station, where it is diminished in size to a diameter of 9 ft. and in capacity (as per majority of commission) to 70,000 gallons a day.

There is a reservoir at Compton Hill with a capacity of 60,000,000 gallons. There are two stand-pipes near Bissell's Point and one overflow stand-pipe at Compton Hill reservoir. The latter acts as an open end to the mains from the Baden high-service pumps. The distribution system on April 1, 1901, was made up of 638 miles of pipe, 7,325 fire hydrants, 67,243 service taps and 4,331 meters.

COST OF SUPPLYING WATER BY PRESENT WORKS.—For the purpose of making comparison between different sources of supply, the process of furnishing water to a city is divided into two parts.

The one which takes the water from its source and delivers it to the distribution pipes, under the necessary pressure, is called the supply works, and their maintenance and operation is the process of supplying the water; the other, which receives the water and conveys it under pressure to the consumer, is called the distribution works, and their operation and maintenance is the distribution of the water.

Construction cost includes pumping works, basins, conduits, reservoir, stand-pipes and 10% of cost of force mains. Operation includes maintenance of system, general expenses, collection of water rates and cost and care of parked grounds. From data carefully collected, the cost of supplying water for 34 years ending Apr. 1, 1901, was:

Total cost of supply works as just defined, to Apr. 1, 1901	$10,297,634
Total expenditures for operating supply works, including repairs and maintenance	6,427,371
Total cost of supplying water	$16,725,005

Continuing the estimate to Apr. 1, 1906, when it is assumed new works may go into operation:

Add to above the estimated cost of operating supply works, Apr., 1901, to Apr., 1906, 126,361 million gallons at $15	1,895,415
Estimated cost of completing present contracts for pumps, etc	748,399
Total to Apr. 1, 1906	$19,368,819

ESTIMATE OF POPULATION AND QUANTITY OF WATER.—The population of St. Louis by United States census has been:

1820	10,049	1850	77,860	1880	350,518
1830	14,125	1860	160,773	1890	451,770
1840	16,469	1870	310,864	1900	575,238

Estimates of population and water required, per year.

		Million gallons.			Million gallons.
1900	575,238	22,994	1940	1,237,000	49,677
1910	715,000	28,689	1950	1,445,000	57,999
1920	872,000	35,004	1960	1,670,000	67,051
1930	1,040,000	42,012			

The experience of cities where the water used is measured indicates that any excess of 60 gallons per capita goes to leakage and waste. The gross amount in St. Louis has been kept below 110 gallons per capita, and when pure water is supplied this amount should not be exceeded. But for short periods the yearly average will be greatly exceeded. We assume that the maximum monthly consumption will be 140 gallons per capita daily and the maximum weekly consumption will be 150 gallons daily per capita.

WATER SUPPLY FROM THE MISSISSIPPI RIVER BY PUMPING AND FILTRATION.

If the Mississippi is to continue as the source there can be but one opinion as to need of filtering as an adjunct to present pumping. Since there is a possible alternative supply from the upper Meramec drainage area, there is required a critical inquiry as to which source promises the nearest approach to an ideal water supply. (Here follows an account of the purification experiments at Louisville, Cincinnati, Pittsburg and Washington, and a statement that while an account of the recent New Orleans studies has not been published, the commission has been able to avail itself of them in part.)

Several filter plants on the Missouri and Mississippi Rivers were visited by the commission, but with little advantage, owing to indefiniteness of results obtained, particularly from a bacteriological standpoint. Louisville is now constructing a rapid filtration plant, and it is understood that Cincinnati will do the same. There is no large plant in existence adapted to the treatment of such water as the Mississippi furnishes at St. Louis. Indeed, it may be said that no city has dealt with such a problem as is presented at St. Louis, because the conditions on the Ohio River, while analogous, differ materially from those at St. Louis.

FILTRATION PLANT FOR ST. LOUIS.—The plan proposed for a filtration plant provides for five baffle walls in each of the existing settling basins, changing the influent pipes to secure a minimum of eddy or current, changing the outlets and providing a lime house.

COAGULATING HOUSE AND BASINS.—After leaving the settling basins the water will pass through a coagulation house, where the coagulant will be applied, then through three coagulating basins, 500 × 260 ft., × 17½ to 20 ft. deep, with a capacity of 19,000,000 gallons each. Between the basins and filters a coagulating chamber is placed where additional coagulant may be applied if desired.

FILTERS.—The filters are to be of masonry, with groined arch roofs. The flow line of the settling basins will be at Elev. 124 (water-works datum); water level at the filters, 123 ft. The effluent from filters will be delivered at Elev. 115, giving 8 ft. loss of head in the filters. The filters, 150 in number, will have an area of 450 sq. ft. each, and a capacity of 1,200,000 gallons each in 24 hours. The sand is to be agitated by air during washing. A stand-pipe 50 ft. diameter and 80 ft. high is provided for wash water. A detailed description of the proposed filtration plant, as prepared by Mr. Hazen, is given in Appendix E (not abstracted) and endorsement of the plan by Mr. Geo. W. Fuller in Appendix I.

SEDIMENTATION.—Observations of suspended solids made at Bissell's Point in 1885-6 and 1887-8, and at Chain of Rocks in 1900-1, are given in Tables I. and II., respectively.

TABLE I.—Suspended Solids in Water at Bissell's Point in 1885-7.*

(Parts per 1,000,000.)

Month	June, '85, to Sept., '86. Raw.	Sept., '86. Subsided.	Sept., '87, to Aug., '88 Subsided.
January	241	57	165
February	570	129	435
March	1,510	204	680
April	1,721	122	317
May	1,583	115	262
June	2,688	87	205
July	2,180	115	384
August	1,384	99	313
September	933	119	148
October	650	62	438
November	533	85	128
December	229	58	192
Average	1,186	104	305

*In 1885-6 raw samples were taken from the distribution well when the basins were being filled. Subsided samples from settling basins near efflux. In 1887-8 samples were taken from clear well from which water was being pumped.

At the time these observations were made the average subsidence period at Bissell's Point was about 36 hours; minimum 24 hours. At Chain of Rocks the average time was 60 hours; minimum 40.

The amount of sediment removed from the settling basins from 1881-95, inclusive, averaged 12.52 cu. yds., and from 1896-01, 11.41 cu. yds. per 1,000,000 gallons. Assembling the data we have:

	Time of Subsidence. Hours.		Sediment, cu. yds. per 1,000,000 gals.	Suspended solids in subsided water. (Parts per 1,000,000.)
	Min.	Avge.		
Bissell's Point, 1885-6.	24	36	11.3	104
Bissell's Point, 1887-8.	23	34.5	12.3	305
Chain of Rocks, 1900-1	40	60	10.1	165

TABLE II.—Suspended Solids in Water at Chain of Rocks, Jan., 1900, to June, 1901.

(Parts per 1,000,000.)

Month.	Raw Water. Missouri Shore.	Raw Water. Intake Tower.	Subsided Water. Outlet Chamber.	Subsided Water. Tap in chemist's office.
January	235	355	82	65
February	370	385	86	56
March	1,925	1,354	290	218
April	2,045	1,144	223	216
May	1,514	1,027	153	132
June	2,600	2,542	194	106
July	2,432	2,483	157	69
August	1,098	1,008	158	99
September	1,154	1,096	130	95
October	2,110	1,088	280	200
November	...	...	...	...
December	233	193	70	71
Average	1,425	1,152	165	121

The evidence shows that Mississippi River water at St. Louis, on the Missouri side, carries not less than 1,500 parts per 1,000,000, and at the inlet 1,200 parts for a normal year. The subsidence, for 60 hours, range from 65% for months of least sediment to 94% for months of greatest. The average yearly efficiency is about 85%. For a 35-hour period the average efficiency was 75%.

Sediment in other Waters compared with Mississippi at St. Louis.

	Parts per 1,000,000	Per cent.
Merrimac River, Lawrence	10	0.8
Hudson River, Albany	15	1¼
Alleghany River, Pittsburg	50	4⅛
Potomac River, Washington	80	6⅝
Ohio River, Cincinnati	230	19
Ohio River, Louisville	350	29
Mississippi River, New Orleans	650	54
Mississippi River, St. Louis Intake	1,200	100

TIME AND EFFICIENCY OF SUBSIDENCE USED IN ESTIMATES.—The commission from the data concludes: (1) There are no known data to fix the proportion which capacities of plain settling basins should bear to amount of water to secure the most economical results in the operation of a filter plant. (2) As some basis of estimate is required, we have assumed what we consider the minimum capacity admissible, viz.: one with which the minimum time of subsidence will not be less than 24 hours, the average time being 36 hours. (3) With such capacity of basins the subsided water will carry an average of suspended matter somewhere between 250 and 300 parts per 1,000,000. (4) With an average subsidence of 36 hours there will be periods of several days during which the effluent water from the basins will contain more than 750 parts per 1,000,000.

SEDIMENTATION AFTER THE ADDITION OF THE COAGULANT.—The plan provides three coagulating basins of 19,000,000 capacity each. The majority estimates that basins must be added in 1925, 1942 and 1957.

The effective capacity of the basins, allowing for deposits, is taken at 17,000,000 gallons each. When all the coagulating basins are in use at the date when new basins are added, the average and minimum hours of subsidence will be:

	All basins in use. Avge.	All basins in use. Min.	One basin out of use. Avge.	One basin out of use. Min.
1925	12	7.5	7.7	5.0
1942	11.7	7.4	8.8	5.6
1957	11.6	7.4	9.2	6.0

If it were possible to settle all the suspended matter in the coagulating basins, and if the sediment occupied the same space that an equivalent amount occupies in the settling basins, there would be about 3.2 cu. yds. of deposit per 1,000,000 gallons. The floculent precipitate will not settle so compactly as plain sediment, and much of it will be carried out of the basins to the filters. The Cincinnati experiments show that when plain subsided water contained 84 parts of suspended matter, 40 parts remained in the water as it went to the filters, after six hours' coagulation and subsidence. With an influent having 750 parts per 1,000,000 for days together we may reasonably infer that 300 parts will pass through the coagulating basins to the filters. And 300 parts is the equivalent of 3.6 cu. yds. deposit for each 1,000,000 gallons which may go to the filters for days at a time.

CAPACITY OF FILTERS.—The 150 filters, of 450 sq. ft. area each, will have a total area of about 1.55 acres, which reduced 20% gives a net area of 1.24 acres. Assuming 5% for wash water the daily average filtered in a year in 1925 will be 111,000,000 gallons, or about 90,000,000 per acre. For days of maximum consumption, 166,000,000, the filter rate would be 134,000,000 gallons per acre. If the time of maximum sediment should occur when the water consumption was at an average for the year, the deposit on the surface of the filters would be about 2½ ins. in 24 hours.

These comparisons represent what is liable to occur and indicate the uncertainties and difficulties of filtering the Mississippi water at St. Louis.

HYGIENIC QUALITIES OF ST. LOUIS WATER.—The drainage area of the Mississippi above St. Louis is 700,-

*Lincoln Trust Building, St. Louis, Mo.
[1]153 La Salle St., Chicago.
[2]39 West Canfield Ave., Detroit, Mich.
[3]220 Broadway New York city.

663 square miles, of which the Missouri drains 527,155; the upper Mississippi, 143,512; and the Illinois, 29,013, not including the area added by the Chicago drainage canal. The total population in cities and towns of over 4,000 population is 4,393,413, distributed by drainage areas as follows: Missouri, 1,090,932; Upper Mississippi, 1,219,645; Illinois River, including Chicago, 2,082,836.

The average results of water analyses (chemical) from Jan. 1 to Oct. 31, 1900, give:

	St. Louis intake.	Upper Miss., Hartford, Ill.	Mississippi Bellefontaine, Mo.
Free Ammonia	0.151	0.275	0.145
Albuminoid Ammonia dissolved	0.194	0.288	0.227
Albuminoid Ammonia dissolved (?)	0.721	0.300	0.876
Nitrates	0.340	0.700	0.500
Nitrites	0.000	0.018	0.007
Chlorine .....13.		8.	16.
Alkalinity .....117.		119.	108.

The above determinations do not show that the water after having passed through a filter would be deleterious to health. They have no special significance except as they may indicate sewage pollution.

BACTERIA.—If the Mississippi River water contains anything prejudicial to health, it must be found in the amounts and kind of bacteria carried.

A reduction of typhoid death rates has almost always followed the installation of a good filter plant. The efficiency of filters is usually expressed in percentages of total number of bacteria in the raw water, but this may be misleading. St. Louis water at times contains 270,000 bacteria per cubic centimeter, and 99% removal would leave 2,700. The Louisville report credits the Warren filter with 96.7% efficiency and the Jewell filter with 96%. The Cincinnati report states that the efficiency varies from 95 to 99.8%. Pittsburg report gives 95.4%. At Washington the efficiency varied from 80 to 99.9%. Bacteria (in the several cases cited?—Ed.) ranged from 135 to 51,000 per cu. cm. The investigations for the Chicago Board of Health from January to September, 1900, show that on the average the natural water of the Mississippi River at Alton contained 37,295 bacteria per cu. cm.; at Bellefontaine, 65,597; at Chain of Rocks, St. Louis, 45,876.

The majority concludes: That there is nothing to show what the result obtained by filters is, relative to disease germs. It is usually assumed that pathogenic germs will be removed in the same proportion as are ordinary water bacteria, but there is no evidence at hand. Filters are not germ-proof. Bacteria applied have passed the filter. Satisfactory results may be obtained if amount of coagulant is unlimited.

INFILTRATION AND CORROSION.—The majority of the commission concludes that the sulphate of alumina used as a coagulant will so raise the contents of the sulphate of lime and carbonic acid in the Mississippi River water as to increase the incrustation of boilers and the corrosion of metal in general. On these accounts, also, it believes that such a supply of water as would be furnished by a mechanical filtration plant with coagulation should be avoided if possible. Althongh the color of the water from this source would be of small consequence, the water might, and probably would, require a greater amount of coagulant to remove its turbidity than if no coloring matter was present. This is suggested by the experiments of Mr. George C. Whipple, and opens a new field of inquiry.

COST OF PUMPING AND FILTRATION PLANT REQUIRED FOR USE DURING TERM OF 55 YEARS.—In order that the cost may be compared with the cost of a gravity supply from the Meramec, the capacity estimated upon must be equal to the gravity supply. In this estimate no account is taken of the value of existing works. Renewal of machinery and structures is included in the estimate. The estimates assume that the existing works at Bissell's Point will be removed from Baden when Bissell's Point pumps need renewing.

Estimates for renewals assume that the filter plant will have a life of 40 years; engines, boilers and foundations, 30; open settling basins, 100; conduit and Baden (pumping station?), 100; buildings, 60; closed reservoirs and underground tunnels, permanent. On this basis the total renewal fund for 55 years would amount to $5,622,583.

ESTIMATED COST OF PURIFICATION WORKS.

Total estimated cost for structures and machinery.....	$6,011,700
New buildings and miscellaneous structures....	1,607,500
Renewal of buildings and miscellaneous structures.....	691,000
Settling basins.....	1,416,000
Clear water reservoirs.....	880,000
Improvement of Compton Hill reservoir.....	308,000
New inlet tower, tunnel and appurtenances ...	333,700
New conduit.....	661,500
Filter plant.....	3,643,000
	$15,552,400
Force mains in excess of gravity system.....	2,300,000
Total (not including main renewals).....	$17,852,400

The estimates cover a pumping capacity at Chain of Rocks, river pumps, 360,000,000 gallons; at Baden for low city service, 180,000,000, and for high service, 210,000,000. It includes practically a duplication of the existing works. It assumes an annual daily capacity of 184,000,000 gallons, which, including renewals for 55 years, would cost $84,524 per 1,000,000 gallons original capacity.

The present plant, when the new engines are in service, will have an annual daily average capacity of 96,000,000 gallons, costing $105,200 per 1,000,000 capacity, without filters, against $84,524 per 1,000,000 capacity for the plant as estimated for 55 years, including filters.

The total cost of structure is estimated at $17,852,300, and of renewals at $5,622,583, making a total of $23,474,983. This sum divided by total amount supplied during 55 years, 2,479,751,000,000 gallons, gives $9.46 per 1,000,000, to which, if $20 be added for cost of operation, makes an average total outlay per 1,000,000 gallons supplied of $29.46.

The cost of supplying water, has, for the last 16 years, averaged $14.88 per 1,000,000 gallons, and for the year ending April, 1901, $14.74. Increase of cost for labor, etc., about balances the economy of new pumps. Coal has varied from $1.06 to $1.52 per ton; in 1900-1 it was $1.32. The price of coal will probably increase. Probably the cost may, leaving out operation of filters, be reduced to something less than $14.74.

The cost of operating a filter plant is uncertain for want of sufficient knowledge of the requirements. For the purpose of this report we estimate 3.5 grains of sulphate of alumina per gallon, or 500 lbs. per 1,000,000 gallons, at 1¼ cts. per lb., $6.25; labor, repairs, etc., $2.25; minimum cost of supply in the past, $13.65; total, $22.15. Hence the $20 per 1,000,000 used in the estimate is at least conservative.

GRAVITY SUPPLY FROM THE MERAMEC RIVER DRAINAGE AREA.

The available sources are the Meramec Spring, the Water Fork, the Dry Fork and the Courtois branch of the river.

The drainage areas are: Water Fork, 344 sq. miles; Dry Fork, 383; Courtois, 501; total, 1,228 sq. miles.

The Huzza River joins the Courtois and is included in its drainage area. The Courtois enters the Meramec 38 miles below the spring, and would be reached by about 20 miles shorter conduit.

The plan of gravity supply includes a reservoir of 400,000,000 gallons capacity at Dwyer, with a flow line 660 ft. above sea level; a reservoir near Forest Park of 150,000,000 capacity, with a flow line of 600 ft.; improvement of Compton Hill reservoir, 60,000,000 capacity, with a flow line of 589 ft. There would be three levels of service.

PHYSICAL CONDITIONS.—Meramec Spring is 781 ft. above sea level, 370 ft. above the Mississippi at St. Louis (low stage), and 180 ft. above the highest points in the city.

The water from the spring unites with the Water Fork about ¾ mile below the spring. The Meramec Spring and bed of the Meramec River is in the third magnesian limestone. The upper water shed of the Dry Fork and much of that of the Water Fork is chert or sandstone. Where third magnesian limestone occurs, water is found in streams and springs. Where chert or sandstone reaches to base of hills no water is seen. The upper surface of the third magnesian limestone abounds in caves, one of which apparently connects the natural storage reservoir in the chert and sandstone formations of the Dry Fork water shed with the outlet of Meramec Spring. A cave has an opening from the bed of Dry Fork into which much of the river flow is discharged at ordinary stages of the stream. The beds of broken sandstone and chert, covering 400 square miles, undoubtedly are the reservoir from which the water of the spring is drawn.

Comparing the variations in flow of the Water Fork and Spring it is found that when general rains fell on both basins, the river and spring commence to rise at the same time, showing that the source of supply for both are within the area covered by the rainfall. The logical conclusion is that the Spring supply comes from the chert and sandstone of the Dry Fork and possibly the extreme southern part of the Water Fork.

QUALITY OF THE MERAMEC SUPPLY.—A very small part of the watershed is now or ever can be utilized for farming purposes. No swamps exist and the soil on the hills is so poor that little organic matter has accumulated with which the water of rains or snow can become polluted or colored. The population, including towns, is 27 per sq. mile for the Dry Fork, 14.5 for Water Fork and 11 for the Courtois. The rural population is less than one-half of these numbers and is not likely to increase.

Chemical and bacteriological analyses show the water to be pure and wholesome, adapted to domestic and boiler use. It has been said that at times of flood the water of Meramec Spring is somewhat turbid and that tributary streams carry considerable suspended silt. These conditions last but a few days in each year and the small amount of sediment carried will likely be dropped in reservoirs and not reach distributing mains. When such floods occur the flow from the Spring will be 150,000,000 gallons per day. Nearly enough to supply the city without using the river water until settled. Water from the Water Fork or Courtois if stored in reservoirs will be as pure as that of the Spring. Some ground waters when exposed to sunlight have a growth of Algae. The plans are for covered reservoirs to prevent such growth.

The monthly mean precipitation, as shown by observations at nine nearby stations, gives an annual precipitation for whole district of 41.65 ins. Two of the stations are in the watershed. Their records cover only a few years. Comparing those records with longer records at St. Louis and Ironton the fact appears that since 1839 no year has had less rainfall than 1901. It is probable from data at hand that during the 62 years (1839-1901) the annual precipitation on the watershed had not been less than 32 ins. until 1901, when it was 24.8 ins. (at Rolla—Ed.). The monthly figures for 1901 are given in Table III.,

TABLE III.—Rainfall and Visible Flow in Meramec Drainage Area in 1901.

		Rainfall and runoff, millions of gallons.			
Mouth.	Rainfall, ins.	Rainfall, Water Fork.	Runoff, Water Fork.	Runoff, Meramec Spring.	Rainfall, Dry Fork.
Jan.	0.87	5,213.6	1,477.3	1,972.7	5,805.8
Feb.	1.70	10,190.0	1,625.9	1,654.2	11,344.8
Mar.	3.32	19,900.0	6,129.8	2,720.8	22,150.0
April	2.99	17,922.0	5,706.3	3,465.7	19,958.5
May	0.73	4,375.7	1,478.6	2,483.9	4,871.6
June	2.30	13,785.3	639.6	1,713.5	15,348.8
July	1.64	9,830.0	423.0	1,488.0	10,944.8
Aug.	1.59	9,530.0	645.3	1,512.8	10,610.7
Sept.	0.92	5,314.3	305.2	907.2	6,139.5
Oct.	2.29	13,726.0	288.9	785.8	15,282.1
Nov.	1.66	9,950.0	350.6	964.0	11,078.0
Dec.	4.79	28,710.6	2,280.0	1,590.0	31,965.5
Total..	24.80	148,647.5	21,446.8	21,259.6	165,499.1

The flow from Water Fork is about 1-7 of the rainfall, or 3.6 ins., but there is probably a large ground flow in a valley 1,200 to 1,800 wide, with sand and gravel 6 to 10 ft. deep below low-water level and a slope of 7 ft. per mile. If all the water had been measured a runoff of about 5 ins. from the watershed is estimated.

The average low water from the Meramec Spring is about the same as that of Water Fork, and about ⅛ of the rainfall on Dry Fork watershed. The average visible flow in the Dry Fork was small, since the stream was dry for over six months. It is safe to assume that for ordinary years of low rainfalls (32 ins.) 8 ins. may be collected, and in extreme dry years (25 ins.) at least 5 ins. If 8 ins. is collected the average yield for the whole drainage area would be 467,000,000 gallons, but if only 5 ins. is collected the total yield would be only 290,000,000 gallons per day.

In an ordinary year the Water Fork and Meramec Spring will yield jointly 260,000,000 gallons, and in a year like 1901, about 150,000,000 gallons per day. To insure a safe supply when St. Louis requires more than 150,000,000 gallons a day, storage reservoirs must provide the deficiency. The plans provide a storage reservoir in Water Fork Valley of 41,400,000,000 gallons capacity, which would furnish 50,000,000 gallons per day from storage for two consecutive years.

It is assumed that with such a reservoir in reserve the Meramec Spring and Water Fork yield may be considered safe for an average of 200,000,000 gallons per day. When need requires an additional supply can be obtained from the Courtois watershed.

CHARACTER AND CAPACITY OF WORKS.—The conduit tunnels and pipe lines are designed to be equivalent to a concrete-lined conduit 13 ft. in diameter, having a slope of 0.0001 and maximum flow of 225,000,000 gallons per day. Two systems of distributing reservoirs have been considered; one with high-level reservoir surface at 700 ft. elevation, which would serve the highest points in the city with a 75-ft. head; the other for high-service reservoir at 660 ft. elevation and a lower reservoir at 600 ft., with pumps at the latter to serve points not properly supplied from high-service mains. The former system gives a simpler scheme, but the lower system is preferred because of better connection with a reservoir on the Courtois and of considerable less cost.

No surveys were made of the Courtois except at a possible dam site, but there are reasons to believe that it may be preferable to construct a reservoir in the Courtois Valley as a principal source of supply and afterwards extend a conduit line to Meramec Spring and Water Fork, when more water is required than the Courtois will safely furnish.

If the plan for a gravity supply should be adopted complete topographical surveys, for location of pipe and conduit lines and of reservoir sites, will be necessary. Such surveys and design of plans would take at least six months. If construction work is commenced and diligently carried on, the system of supply can be ready for use in four years from commencement of surveys. Estimates of cost are given in Table IV.

Table IV. Estimated cost of Works, Operation and Maintenance.

Storage dams and gate-houses in Water Fork Valley and at Meramec Spring....	$2,258,000		
Grubbing and clearing reservoir site	1,150,000		
Lands, damages and rights of way.	900,000		
Public highways	30,000		
Changes of railroad line.....	200,000		$4,538,000
Conduit, tunnels and pipe line.....			$14,901,000
Covered reservoir at Dwyer.....	964,000		
" " " Forest Park....	750,000		
" " " Compton Hill...	280,000		1,994,000
Steel pipe from reservoir and city distribution system			3,586,520
Total....			$25,020,420
Engineering and superintendence...	$2,502,042		
Interest during construction.....	1,788,960		
Financiering....	2,767,278		
	$7,058,280		

Less credit from sale of water-works, land, etc.	1,078,700	5,979,580
Total estimated cost		$31,000,000
Official estimate of surplus income from water rates from 1901-'06		$6,469,000
Amount needed for distribution pipes, 1901-'06		2,469,000
Surplus available for gravity supply		4,000,000
Cost of gravity supply		31,000,000
Bond issue required		$27,000,000
Interest on $27,000,000 at 3¼%		$877,500
Sinking fund to redeem bonds in 40 years		338,580
Maintenance and operation		100,000
Renewal fund, pipes and conduit		38,000
Taxes		20,000
Annual expense for 40 years		$1,374,000

Average cost per 1,000,000 gallons, to meet payments for 40 years, $34.40.

Average cost per million gallons for 54 years, 1906-1960, $23.30.

If the higher-service system elevation, 700 ft., is adopted, the estimates must be increased $2,000,000. If the Courtois alternative is taken the cost would be reduced about $2,500,000.

COMPARATIVE HARDNESS OF MISSISSIPPI AND MERAMEC WATER.—Direct determinations of hardness of Mississippi and Meramec waters have been made at various times by several chemists, but the results are not in accord. A probable value is 8.4 for Meramec and 13.72 for Mississippi water. As to permanent hardness, the difference in favor of Meramec water is very great. The average of "incrusting constituents" for the four determinations for Meramec water is less than 6 per 1,000,000, and the yearly average can hardly exceed 3 parts. The (corresponding—Ed.) yearly average of sulphates in raw Mississippi water is about 71 parts, and in filtered water would be probably about 99 parts. This superiority of the Meramec water will be worth to the city of St. Louis several million dollars.

FINANCIAL COMPARISON OF PROJECTS.—The estimates make the cost of supplying water by pumping and filtration during 55 years at $9.46 for structures and renewals and $20 for operating expenses, a total of $29.46 per 1,000,000 gallons. This includes nothing for interest. For the gravity plan, for a period of 54 years, the estimated cost is $23.20 per 1,000,000 gallons. If $31,000,000 bonds are issued the cost will be $26.

Another comparison can be made by reducing operation, renewals and construction outlays to their present worth, or a sum which put at interest at 3¼%, will meet all expenditures. On this basis, pumping and filtration would represent:

Construction expenses		$9,510,000
Renewals		3,046,000
Operation, at $20 per 1,000,000 gallons		27,180,000
Total		$39,736,000
Against, for the gravity plan, a total first outlay of	$31,000,000	
Operating expenses and renewal fund capitalized	4,861,000	35,861,000
Difference in favor of gravity works		$3,875,000

This difference is but a small part of the financial advantage of the gravity plan. If the pumping and filtration plan is adopted it would in effect make a perpetual debt to the amount of the present worth of the renewal fund and operating expenses, or $30,226,000. When the first cost of gravity plan is paid off the perpetual debt would be only $4,861,000. It is true that the cost per million gallons will for some years be higher for the gravity than for the pumped supply.

GENERAL CONSIDERATIONS AND CONCLUSIONS.—The estimated time for construction of filtration plant is three years; for gravity supply, four years. It would be very unsafe to design plans for filtration of Mississippi water at St. Louis without extended investigation as to cost and requirements for a clear, wholesome supply of water by filtration. Such investigation would require one or two years. The gravity supply plan is sound economic policy since it utilizes natural forces, which otherwise will be lost, while the pumping plan perpetuates such waste. Pumping and filtration seeks to alleviate evils rather than avoid them; the evils to be alleviated will continue, if not grow in magnitude. A gravity supply from such a source as the upper Meramec watershed is a near approach to the ideal. Granting all that may be said as to artificial methods of purification, there is no reason to accord first place to any water which from natural or artificial causes has once become ladened with silt or organic pollution.

(Signed) Benezette Williams.
Geo. Y. Wisner.

St. Louis, Mo., Jan. 27, 1902.

MINORITY REPORT.

I am unable to agree with the majority of the commission that a water supply can best be obtained from the Meramec watershed. I believe that the best interests of the city will be served by continuing to use water from the Mississippi or Missouri River, with the addition of filtration. I recommend the construction at once of a complete purification plant at Chain of Rocks.

I have made preliminary plans for a purification plant with a net capacity of 150,000,000 gallons per day. These plans have been examined and are endorsed by Mr. George W. Fuller.

The total estimated cost of the works at Chain of Rocks is, for 150,000,000 capacity, $1,948,000. Changes and additions to other parts of the works include a 50,000,000-gallon covered reservoir at Baden, $440,000; covering and raising Compton Hill reservoir, $308,000; making estimated cost of all structures now recommended $2,696,000.

REASONS FOR RECOMMENDATION.—(1) On the basis of estimates of cost adopted by the majority the purification plant is, for many years at least, more economical.

The first comparison made by the majority is defective because it overlooks the matter of interest. For the early years of the assumed period the river supply is much the cheaper. In the later years it is more expensive. If the surpluses of the later years were available as cash to meet deficits of the earlier years the comparisons would be fair; as they are not, the sums should be discounted.

A fair comparison is to put side by side the costs involved by each project for various years. I assume as the date of beginning, January, 1906. For the pumping supply I take the expenditures for capital and depreciation as stated by the majority, and for cost of operation multiply the estimated consumption by $20 per 1,000,000 gallons. For the gravity supply I take the amount estimated as available surplus funds at the end of 1905, and at the end of each year add the charges for the gravity supply. I take the difference between charges for gravity supply and pumping supply and compute them as a fund invested at 3¼%.

The balances in favor of filtration thus found increase from $4,799,000 in 1910 to a maximum of about $29,000,000 in 1944, an amount equal to the entire estimated cost of the gravity works. From 1944 on the balances decrease to $19,825,000 in 1960.

All works for continuing the river water supply can be built out of revenue, and the works can be abandoned without residual debt after 20, 40 or 60 years, if conditions make it advantageous to do so.

(2) Some important matters have been left out of the account. Of the sale value of land at Bissells Point, nine-tenths of this land is as useless for proposed Mississippi River supply as for the gravity supply. The former should be credited with, say $450,000, and with $1,750,000 as the value of purified water for the two years the filters could be in service before a gravity supply is possible.

These two sums combined and capitalized at 3¼% would amount to over $7,000,000 in 1944, and over $11,000,000 in 1960. These amounts should be added to the figures in the preceding table.

(3) The estimates for the river works are relatively higher than for the gravity works. The estimates are usually higher than cost of constructing similar parts of present works. I believe that nearly all parts of the existing works could be reproduced at prices as low or lower than they cost when constructed.

The majority estimates the cost of six settling basins, with a combined capacity of 174,000,000 gallons, at $1,416,000. It estimates the cost of a 150,000,000-gallon covered reservoir for a gravity supply at $825,000, and a 200,000,000-gallon reservoir at $1,060,400. That is, open sedimentation basins for a river supply are estimated to cost more than covered reservoirs for a gravity supply. I believe this is most unfair to the river supply.

CAPACITY OF WORKS.—The capacity of a gravity supply, assuming that water is available at the source, is limited by the capacity of the conduit. This is to be equivalent to that of one 13 ft. in diameter, with a slope 0.0001. The hydraulic radius would be 3.72 ft. The new Croton aqueduct to a level giving this hydraulic radius had a discharge corresponding to coefficient 134.32 in Chezy's formula. With this factor I compute the discharge of the proposed conduit, new and clean, at 218,000,000 gallons in 24 hours. If a reduction of 10% results when the conduit becomes dirty, the capacity would be only 196,000,000. Adding 5,000,000 drawn from storage I make 201,000,000 gallons per day as the maximum monthly consumption that could be maintained by proposed conduit.

The capacity of the source, 184,000,000 gallons a day, is also estimated higher than existing data will justify. (Argument omitted here—Ed.).

The structures contemplated for the river supply have a much greater capacity. Two intakes will pass 393,000,000 gallons per day. Pumps at Chain of Rocks are proposed of 360,000,000 daily capacity. Filters, settling basins and appurtenances are proposed for a net supply of 300,000,000 gallons per day. Two conduits are proposed from Chain of Rocks to Baden of 260,000,000 gallons estimated capacity (actually 350,000,000). Pumps at Baden are proposed of 390,000,000 gallons capacity. The whole proposed plant is on a 300,000,000-gallon basis, and will furnish a higher average daily supply than can be safely drawn from the gravity works.

The majority estimate makes no allowance for contingencies. In my judgment a substantial allowance should be made. Not the least contingency is that the proposed dam will not hold water. The underlying rock is often cavernous. The Meramec Spring is itself direct evidence of a cavern. Depreciation is in my opinion underestimated by the majority in all cases, since the sums are larger this underestimate is to the advantage of the gravity supply.

The cost of operating the river works by the majority estimate is too high, though based on official reports of expenses. Repairs are charged as operating expenses; also care and parking of grounds. Cost of pumping at Bissell's Point is excessive and should be redu[illegible] future to the cost of Baden. Estimated cost of o[illegible] river works:

Cost of pumping at Chain of Rocks, as at pr[illegible]	$3.13
Care of settling basins, as at present	15
Operation of filter plant, estimated	7.43
Cost of pumping at Baden, as at present	6.50
Care of grounds, conduits and railroads, estim[illegible]	1.00
Total cost of operation per million gallons	$18.21

This estimate would pump all the water [illegible] high-level service and makes no allowance for the p[illegible] delivered at lower level.

The estimate of $20 by the majority could b[illegible] by good management of the works.

DIFFICULTIES OF PURIFICATION HA[illegible] BEEN OVERESTIMATED.—(4) As to physical difficul[illegible] in ope-rating the plant successfully, I believe there are [illegible] that cannot be successfully met. True, the water at [illegible] Louis is difficult to treat, and will require more thorou[illegible] methods than are needed elsewhere. The plant as desig[illegible] is far more complete than any plant ever constructed. To some extent the work is novel and experimental, but the important matters are well understood from experience with similar waters. The estimates are based on treating water as bad or worse than records show St. Louis water to be. If unexpected difficulty is developed, the margin between my estimate and that of the majority will cover any contingencies that may arise.

I believe the hygienic character of the purified water will be satisfactory. True, the river carries very large numbers of bacteria, washed by rains from the rich soil of the watershed, but so far as there is danger to health in the present water, it will be reduced by filtration to an almost inappreciable amount.

If found desirable the supply can be drawn from the Missouri River by gravity to the Chain of Rocks works. A tunnel four to five miles long, with 300,000,000 gallons capacity, would cost about $1,500,000.

I believe the filtered river water will be reasonably satisfactory for mechanical uses, and that there will be no seriously objectionable results from the use of a coagulant. The water cannot be satisfactorily treated without a coagulant. The alkalinity is ample to neutralize the coagulant required. The alkalinity at St. Louis is much greater than that of the Ohio River and there will be less danger of the production of conditions that will corrode pipes or otherwise be injurious than at Ohio River cities. The raw water contains practically no free carbonic acid and is saturated with oxygen.

In soap-consuming power the filtered river water will not differ materially from the Meramec water. It will differ in that some of the lime will be in the form of sulphate instead of carbonate. The sulphate is more objectionable in boilers. I believe the sulphate of lime in the filtered water is very largely overestimated in the majority report. I had not supposed and do not believe that this matter will give serious trouble.

When we saw the Meramec Spring the water was perfectly clear, but it is sometimes turbid. We have no information as to how turbid it gets or how long the turbidity lasts. The water from the impounding reservoir will hardly have a turbidity less than that due to from 3 to 20 parts of suspended matter per 1,000,000 gallons. This will be so fine as not to be removed in conduits and reservoirs. Filters will give an entirely clear effluent.

In sanitary quality I believe the purified river water fully equal to the gravity supply. The water of Meramec Spring is largely surface water from the Dry Fork, coming through caverns without long storage of filtration.

In physical appearance the filtered water will be best. For mechanical purposes it will be as good. For boilers it will be less desirable, but I do not believe the difference will be great. All things considered, I believe the quality of the purified water will be at least equal to water from Meramec Spring and River.

ON THE BASIS OF PERPETUAL CAPITALIZATION THE RIVER SUPPLY IS CHEAPER.—Capitalizing operating expenses and discounting all values to one selected time is the most searching test which can be applied to projects of this character. It involves an assumption not in accordance with the facts; namely, that the consumption of water will increase regularly to the ultimate capacity of the gravity works, and will forever after remain at that figure. Additional works would then be required, which, in the case of the gravity supply, would be much more expensive at first than the necessary addition to the Mississippi River plant; if the time of comparison should be taken at any other point than the ultimate capacity of the gravity works, the comparison would be more favorable to the river supply. As such stopping points occur only at intervals of long periods of years, some unfairness to the river supply is involved in this method.

Waiving this, I will take up the comparison on the lines used by the majority of your commission, and repeat the computation made by them, with these modifications: That the cost of structures for the river supply, discounted, is to be taken only for a period of 40 years, at which time the proposed structures for the river supply will more than equal the capacity of the proposed gravity supply; and that thereafter the operating expenses be capitalized on a basis of 160,000,000 gallons per day, in-

...d of 184,000,000 gallons, 160,000,000 being slightly ... than the average capacity reached in 1900, at which ... the capacity of the aqueduct moderately dirty will ... reached during the months of maximum consumption; ... that the two items, hereinbefore mentioned as ... in the comparison, be included.

... cost of the river project, revised, is as follows:

... works required, and depreciation charges ... to and including 1945, discounted to Jan. 1, 1906.....	$10,670,000
...oximate discounted value of operating ex...enses for the years 1906 to 1945, inclusive, ... $20 per 1,000,000 gallons, Jan. 1, 1906....	16,060,000
...rating expenses after 1945, 160,000,000 gal...ons per day, at $20 per 1,000,000 gal...lons, $1,162,000 per annum; capitalized at ...¼%, $35,960,000; discounted for 40 years..	10,006,000
...preciation charges after 1945, $158,577 per ...nnum; capitalized at 3¼%, $4,879,000; dis...unted for 40 years.....	1,358,000
Total cost of building and operating river works for ever, with an ultimate capacity of 160,000,000 gallons per day, discounted to Jan 1, 1906.....	$38,094,000
Deduct sale of Bissell's Point property and value of pure water supplied two years earlier.....	2,150,000
Net discounted cost, river supply.....	$35,944,000
Corresponding cost of gravity supply, as computed by a majority of your commission..	$35,861,000

On the above basis the costs as discounted are substantially the same. If, however, the cost of operation is taken at $18.21 per 1,000,000 gallons, the saving in discounted operating expenses amounts to $2,330,000, and this sum will stand to the credit of the Mississippi River works.

Even neglecting the reduction in operating expenses, I believe that the advantage is with them.

Let us see what is involved in the two projects. For the river works the plant now required would cost $2,700,000. For the gravity plant the works would cost $31,000,000, in addition to the salvage from the old works. In my judgment it is not enough to show that new works involving so large an expenditure can be constructed on a basis such that, at 3¼% interest, the cost will not be greater than continuing the present works. The city ought not to take up an enterprise of this sort unless it can be assured of a substantial profit above the interest commensurate with the risks involved in lending its credit to so large an undertaking.

Jan. 31, 1902. (Signed) Allen Hazen.

FILTRATION ENDORSED BY MR. GEO. W. FULLER,* ASSOC. M. AM. SOC. C. E.

Mr. Hazen's report was supplemented by a communication from Mr. Fuller dated Dec. 6, 1901, and a second one, dated Jan. 31, 1902. The first letter was a general endorsement of Mr. Hazen's report, including his estimates of cost.

In the second letter Mr. Fuller says: Works for the successful and economical purification of the Mississippi River water involves three distinct portions, namely, sedimentation basins, coagulating basins, and filters. As the evidence now stands concerning the purification of turbid waters, it may be definitely stated that the raw river water should be given a preliminary treatment, so that as it reaches the filters it would contain not more than 50 parts per 1,000,000 by weight of suspended matter, and preferably less. So far as filtration proper is concerned at St. Louis, the project involves no problems materially different from or more difficult than a number of others which have been considered in great detail, and for which works are now being constructed.

As to the efficiency of the American or mechanical type of filter, it is manifestly unfair to give them a rating based on results obtained during the period of development of the process. As the art stands to-day, based on lessons learned during the past eight years, no apprehension need be had on the score of these filters being capable of doing satisfactory work.

It is in the preparatory treatment of the Mississippi River water at St. Louis that the project in question possesses distinct individuality. Starting with the proposition that the raw river water must be given a preliminary treatment by sedimentation and coagulation so that the water as applied to the filters will not contain more than 50 parts per 1,000,000 of suspended matter, it is necessary to determine how the division of work can be most judiciously made so far as relates to the first two steps in the complete process of purification. Obviously, plain sedimentation should be provided to such a degree that a further clarification can be accomplished through the aid of coagulation and supplementary subsidence as cheaply as, or cheaper than, by the continuance of plain sedimentation.

The opinion has been expressed that plain sedimentation ought to be extended to at least 36 hours. I would say that this view does not coincide with my interpretation of the facts at hand. As to the efficiency which has been accomplished by settling basins at St. Louis, the data concerning the suspended matter in the raw and settled water during the years 1887 and 1888 indicate that the river water was fully 50% more turbid on an average than for a normal year. For the year 1887-8 the average reduction of suspended matter in the river water by settling was from 3,000 to 302 parts, or a reduction of approximately 85%. During the year 1901, the reduction was from 1,152 to 165 parts, which is also equal to a removal of about 85%. As I understand the record, the average period of sedimentation during these two years were about 36 to 50 hours, respectively.

After looking carefully over all the available evidence, I am satisfied that an estimate of about 200 parts per 1,000,000 of suspended matter is a conservative one for the average composition of the subsided water at St. Louis after treatment for 24 hours in basins well baffled. This corresponds to an average removal of about 83%, when the average suspended matter in the river water is taken at 1,200 parts. It is my opinion that your conclusions in this respect are perfectly sound.

From recent studies at New Orleans, it has been found that under local conditions the economy and efficiency of purification works are not very materially affected by the period of plain sedimentation within the limit of 12 to 48 hours. The coarse matter in the Mississippi water at both St. Louis and New Orleans settles quickly, and with it goes a very large portion of the organic matter which is attached to the suspended particles, and which, if not removed, would cause a considerable waste of coagulant.

With regard to the capacity of the coagulating basins, information now available upon this general subject enables us to consider it in a very satisfactory manner. The quality of the water to be coagulated upon entering these basins would approximate the composition of the water now leaving the present settling basins. With such a water twelve hours on an average for supplementary sedimentation following coagulation is an ample period.

As to the amount of coagulant estimated to be necessary in treating the St. Louis water, three grains per gallon on an average, I think that this is liberal, and that it is not at all unlikely that in practice it would be found that 2½ grains would suffice.

Relative to the corroding action of filtered water at St. Louis on pipes, metals, etc., and of probable trouble from permanent hardness or incrusting constituent, the water in this respect would be reasonably satisfactory, and much more so than a large number of unfiltered waters now being used throughout the central portion of this country.

It must be remembered that it is a perfectly practicable proposition to eliminate all of the added incrusting constituents and carbonic acids by means of further treatment, and at a moderate cost, say not exceeding about $2.50 per 1,000,000 gallons, should it ever be found that such treatment would prove advisable. In my judgment, if purification works are adopted, such treatment would never be needed.

SUPPLEMENT BY MAJORITY.

The majority of the commission submitted a supplement to their report discussing the points raised by the minority. Much of this supplement relates to details and data not given in this abstract. The majority disputes the estimate of 218,000,000 gallons as capacity of the conduit when new, and claims that when dirty it would pass 240,000,000 gallons, using coefficients determined for the Croton and Wachusett aqueducts.

The commission further considers the case of New Orleans and says:

Neither Mr. Fuller's supplemental report nor the minority report furnishes any new data or knowledge as to these matters. It is not apparent what justification your commission could have at this time for recommending any system of filtration for St. Louis. The St. Louis problem is certainly as difficult of solution, and as complex as the one at New Orleans, and it should not be entered upon with less caution. As no information is available to the St. Louis commission that was not available to the New Orleans commission when they entered upon their work, it is manifest that the plant best adapted for filtration at St. Louis, its cost and efficiency must remain an open question, until full experimental investigations are made.

*Of Hering & Fuller, 100 William St., New York city.

THE BROOKLYN BRIDGE TERMINAL PROBLEM has received a new solution by Bridge Commissioner Gustav Lindenthal, M. Am. Soc. C. E. The principal features of the new plan are summarized as follows in "The Tribune" of March 4:

It provides for the purchase by the city of the triangular block between Park Row and North William St., north of the bridge entrance, and the entire block on which the "Staats-Zeitung" Building stands, bounded by Tryon Row, Centre St., Chambers St. and Park Row.

It provides for an elevated railroad connection between the existing Brooklyn Bridge and the new Williamsburg Bridge, by way of the existing elevated railroad route along Park Row and the Bowery.

It provides for a commodious terminus for the Manhattan Elevated R. R. of double the capacity of the existing City Hall station, which would obviate the crowding at that station.

It provides for the extension of the Navy Yard Bridge by means of a two-track elevated structure along Canal St., to the west side of the Borough of Manhattan.

It provides for a loop under roof of the Fourth Ave. surface cars.

It would permit a direct connection from the City Hall station of the Manhattan Elevated Railroad by way of Second Ave. and the Blackwell's Island Bridge to Ravenswood.

It provides for a ready and an unobstructed access from the underground station near the Brooklyn Bridge entrance to the bridge station.

It provides for use at three suspension bridges of moving platforms as a means of transporting the largest possible number of passengers during rush hours.

Outgoing passengers will be landed by staircases on a stationary platform. They will step from it upon the 2½-mile platform, thence on the 5-mile and 7½-mile platforms, and finally to the 10-mile cars, the seats of which will be placed 10 ins. from the edge, as was done at Chicago. Incoming passengers will reverse these operations.

It provides for the removal of the "hideous bridge buildings," both in Manhattan and in Brooklyn and the replacing of the same with serviceable and useful structures possessing architectural merit.

The estimated cost of the entire improvement is estimated at $14,500,000.

THE ELECTRO-PNEUMATIC BLOCK SIGNALS on the Pennsylvania R. R. were severely tested in the late storm which played such havoc with overhead wires. The system operates its wires in tubes, and all signals were set with perfect regularity and without the slightest interruption. The entire New York Division of this road is equipped with the electro-pneumatic block signals; and so is the main line from Philadelphia to Paoli, and about two-thirds of the line between Altoona and Pittsburg. The Atlantic Division of the West Jersey & Seashore R. R. is so equipped and the system is being extended to Washington and west on the main line as fast as the extensive improvements being made on these lines will permit.

THE NEW YORK RAPID TRANSIT RAILWAY.

V.

Sewer Diversion.

The underground portion of the New York Rapid Transit Railway cuts the sewer system of Manhattan into two separate parts for a distance of about 13 miles. A comprehensive readjustment of the system was, therefore, required to adapt it to the new conditions. Indeed, so extensive were the changes required, and so important was the work considered, that a separate division of the engineering staff of the Rapid Transit Commission was organized to plan and carry out a general system of sewer diversion for the entire subway and tunnel line. Mr. Calvin W. Hendrick, M. Am. Soc. C. E., was placed in charge of this division.

PREPARATORY WORK.—The sewer system of New York city has grown gradually from small beginnings. Some portions of it are practically new and other portions are of great age, comparatively. As the result of this the conduits vary in form, construction, dimensions and perfectness of workmanship, and are in various stages of repair and neglect. Generally speaking, however, the plan of arrangement is uniform. The sewers run along the streets and avenues and discharge in groups into mains in the lower-lying cross streets, these mains leading to outlets into

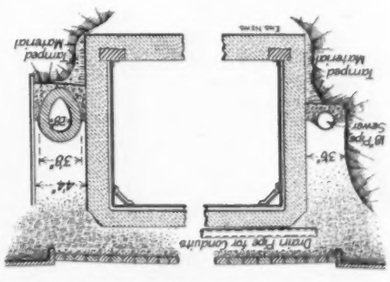


Fig. 11. Diagram Section of Subway, Showing Intercepting Sewers at Each Side.

the North River or the East River, according to the topographical conditions of the locality. It was obvious at the outset that the subway work would involve some change in the arrangement of the sewers, and that this change would affect not only the conduits which actually crossed the line, but would extend to a greater or less distance along the connecting conduits. To know the exact extent of the disturbance it was necessary to know definitely what the actual conditions were. At first it was thought that these conditions could be determined from the plans and records of the Department of Sewers of the city, but a little investigation showed that these plans and records could not be depended upon for the information desired. For this reason it was decided to make a complete survey of all the sew-

ers which would by any possibility come within the circle of influence of the subway work.

The sewer survey was planned and carried out on a comprehensive scale. Briefly described, it comprised a complete sewer map for location; measurements at every manhole for depth and

Fig. 12. Section of Brick Intercepting Sewer Under Construction, Showing Method of Temporarily Diverting the Sewage Flow Through an Iron Pipe.

profile; measurements of cross-section; determination of flow, drainage area and run-off, and, where the dimensions permitted, a careful interior examination of the main throughout its length. The various facts developed by these studies were embodied in maps and profiles of an unusually elaborate character, and they furnished the data upon which a general plan of rearrangement could be based.

From a study of the sewer maps and profiles it was found that the effect of the subway was to introduce an artificial summit running lengthwise

Fig. 14. Section of Vitrified Pipe Intercepting Sewer Under Construction.

of the city, and about midway between its two water fronts. It was decided to recognize this physical division, and, so far as was practicable, to consider the sewers on the opposite sides of the subway as independent systems. All the cross sewers cut by the subway were, therefore, emptied into intercepting sewers built parallel and close to the side walls of the subway masonry, as indicated by the diagram section, Fig. 11. These intercepting sewers continued along the subway to the first available low-lying street main emptying into the river. They were in no sense continuous sewers the whole length of the subway, but were a succession of disconnected links, each of which received the flow of a group of cross-street sewers and took it to a common outlet for that group. As each link of intercepting sewer was independent of the preceding and succeeding links, and had a duty to perform which was peculiar to the locality it served, it had a form and dimensions peculiar to itself. Thus, as shown by the diagram, Fig. 11, the sewer on one side of the subway structure might be a simple vitrified pipe, and that on the opposite side a built-up brick sewer of considerable size.

GENERAL CONSTRUCTION.—The great variety of conditions to be met rendered it necessary to use practically all of the standard types of sewer construction now employed by engineers. Generally, the sewers were planned to be of vitrified pipe, brick or concrete, and to be circular or polycentric in section, but wooden stave pipes are used in special locations, as are also sewers of box section. The specifications for material and workmanship were unusually exacting. The following is an extract from the specifications of the principal clauses relating to brick sewers:

In the construction of brick masonry, none but the best quality of whole North River bricks, burned hard entirely through, will be used; they are to be culled as they are brought on the ground, and all bats and all bricks of improper quality are to be immediately removed from the work. The bricks are to be thoroughly wet by immersion immediately before laying. Every brick is required to be laid in a full joint of mortar, made as described in these specifications, on its beds, ends and sides, at one operation. In no case is mortar to be slushed or grouted in afterward. The bricks are to be neatly and truly laid, every second course by line, and the joints to be carefully struck on the inside, and the sewer is to be coated on the outside with natural cement mortar 1 in. in thickness, mixed in the proportion one cement to one sand.

All brick work, as it progresses, must be racked back in courses, and in no case will it be allowed to be toothed, unless by special permission in writing from the engineer. All inverts, or bottom curves, are to be worked from profiles accurately made according to the dimensions of the sewer, and correctly set according to the grades furnished. The same shall be allowed to set for 24 hrs. before the arch is turned. Vitrified stoneware inverts will be used when required by the plan of the work, and whenever so used they must be thoroughly jointed so as to be water-tight along the inner surface of the sewer, in such manner as the engineer shall direct; and when required by the engineer the internal space of the invert blocks is to be solidly filled with concrete made as described in these specifications and well rammed in as each invert block is laid.

The upper curves of arches to be formed on strong centers of correct form and dimensions, according to the sizes and shapes required. The crown is to be keyed up with stretchers, in full joints of mortar. The centers shall not be removed or withdrawn in less than 36 hrs., and until the work is thoroughly set and the filling of earth is properly put in to place a depth which is at least 1 ft. above the crown of the arch. The centers shall then be drawn or struck with care, so as not to crack or injure the work. All fresh work must be carefully protected from injury in any way. No wheeling or walking on it will be allowed, and any portion injured must be relaid by the contractor.

Unless otherwise permitted, vitrified sewer pipes or spurs, with heels molded thereon for house connections, and equal in every respect to those described in these specifications, and of not less than 6 ins. interior diameter, and of sufficient length to project at least 4 ins. beyond their interior, are to be worked into the walls of brick or pipe sewers at an angle of about 45°, and in the direction of the flow of the current. They are to be built in wherever similar house connections exist in the present sewer which is to be reconstructed under this contract. In the case of the construction of new sewers where no sewers existed perviously, except sewers under public parks or crossing intersecting streets, they are to be built in opposite each house, and where there are no houses, at an average distance apart of 7½ ft. opposite all lot fronts; they are to be so set that their inner ends will be flush with the inner face of the sewer, which end must be molded or trimmed to the same curve. They are to be set at such height in the walls as the engineer may direct, and each pipe or spur is to be closed outside by inserting an earthenware cover made for the purpose.

Fig. 12 illustrates quite clearly the construction specified in the clauses just quoted; the saddle-shaped foundation bed, the ends of the rings racked back in courses, and the vitrified pipe house connections are all shown. This v... shows the manner of handling the sewage ... construction. In several instances this ... interesting feature of the work, where t... sewer replaced an old one, generally of ... size. In such instances of reconstructi... method adopted for performing the wor... to cut out for reconstruction at one time ... section only of the sewer, and to place ... porary iron pipe to carry the sewage by th...

Fig. 13. View Showing Dam of Sand Bags at Intake End of Iron Pipe, and a Short Section of Box Sewer Under Construction.

out. A succession of these short sections completed the new sewer. Referring to Fig. 12, it will be seen that the new sewer has been completed to a point in the background of the picture, and that work is in progress toward the observer on the succeeding cut-out. To the back of the observer is the open end of the old sewer, and from that point to the open end of the new sewer there runs a suspended iron pipe which takes the sewage flow across the cut-out section on which work is in progress. The stream dis-

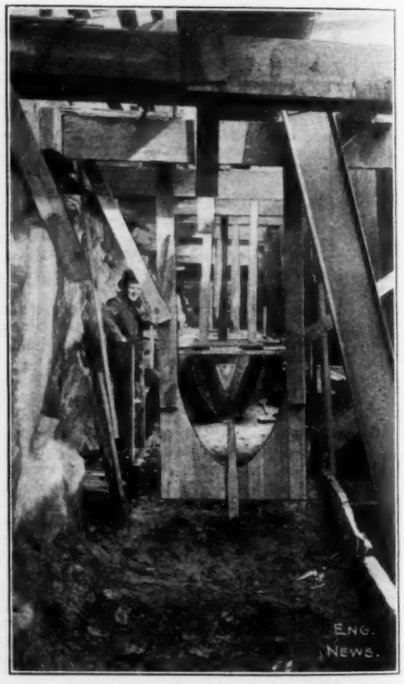


Fig. 15. Template for Alining Invert Form for Concrete Sewer.

charged from the pipe and the temporary dam of sand bags constructed to prevent a back-flow of the discharged sewage are clearly shown. At the opposite end of the pipe a similar but somewhat more extensive dam of sand bags is built, as shown by Fig. 13. This illustration is also interesting as showing a short piece of box-sewer construction.

A typical example of pipe sewer work is shown by Fig. 14. In this view the solid concrete wall to the right is the outside of the side wall of the subway, alongside of and parallel to which the sewer is built in conformity to the general plan already described. The specifications for pipe-sewer work called for a high quality of material and unusual excellence in workmanship, but were not otherwise of particular interest.

In a number of instances the sewers were built of concrete molded in place at a cost of about one-third less than that of brick sewers of the same dimensions. The method of constructing these sewers will be explained by describing briefly a specific piece of work, namely, the 3-ft. 6-in. × 2-ft. 4-in. sewer between 54th and 58th streets. For this sewer the forms for the invert of the straight lengths of sewer were 12 ft. in length, consisting of a strong framework covered with closely-matched lagging planed smooth and greased with machine oil. The arch centers, or forms, for the upper half of the sewer, were constructed in exactly the same way as those for the invert.

The method of construction was as follows: Previous to setting the invert form in place for constructing a length of invert, concrete was placed on the bottom of the trench in a layer thick

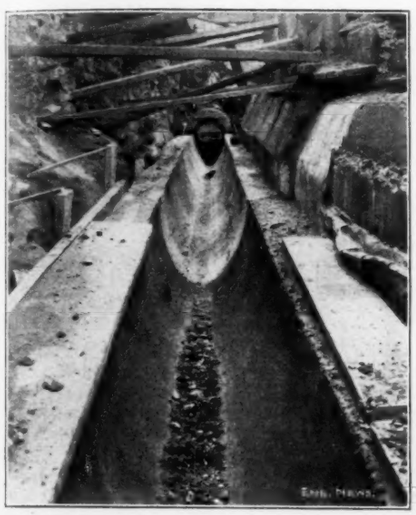


Fig. 16. Completed Invert of Concrete Sewer, with Subway at the Right.

enough to bring its top surface up to within from ½-in. to ¼-in. of flow-line grade. To ensure the accuracy of this work and also to ensure the accurate alinement of the form a template was suspended from the trench timbering and adjusted to line and grade, as shown clearly by Fig. 15. After placing the bottom layer of concrete the form was accurately set in position by resting its rear end on the end of the last completed invert and supporting its forward end on a foundation accurately set to grade. The flow line was then accurately formed by filling the space between the bottom of the form and the concrete foundation layer with a mortar of one part Portland cement to one part sand. The form was then firmly braced in position by struts nailed to the trench sheeting and vertical planking was set up to form the outside of the spandrel. The concrete was then placed and carefully rammed against the form so as to ensure a smooth surface. The invert concrete was composed of one part Portland cement, two parts sand and four parts of stone broken to pass a 1-in. ring. This mixture was placed (not dropped) into position and carefully rammed. The ends of each successive section of invert were mortised to ensure a firm and intimate connection with the next section, and 2 × 4-in. strips, laid longitudinally along the center of the tops of the sidewalls of the invert section formed mortises for bonding the arch ring to the invert. The forms were left in place at least 24 hours to allow the concrete to set. After the invert was set and the form withdrawn a thin cement wash was brushed over its surface to smooth any slight roughness. This work gave a surface almost polished in comparison with the best brick-work. Fig. 16 shows a section of completed concrete invert. In passing this illustration it may be noted that at the right will be seen a portion of the upper

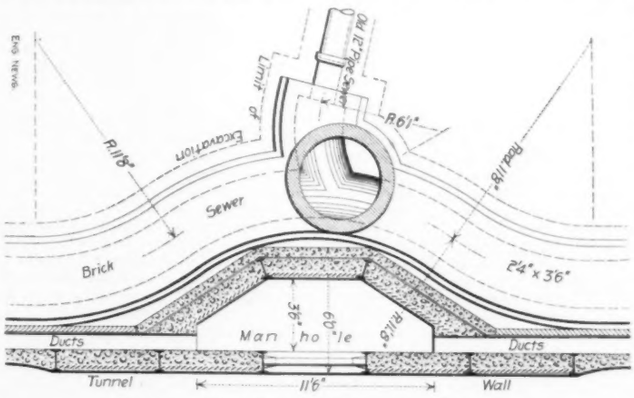


Fig. 18. Typical Plan for Alinement of Brick Sewer Around Electric Manhole.

part of the subway sidewall curving over to a connection with the roof, and also some of the waterproofing.

As already stated, the arch center or roof forms for concrete sewers were of the same length and similar in construction to the forms for the invert. These centers were placed in position as shown by Fig. 16, so as to make the interior of the sewer a continuous smooth surface. In constructing the roof arch, a layer of one part cement to one part sand mortar 1 in. thick was plastered over the form and on this was placed the concrete until the arch had a thickness of 8 ins. Battered side-boards held the concrete from sliding and the top was curved by hand to form the arch.

The sewer resulting from the method of construction which has been described was abso-

Fig. 17. Sewer, with Concrete Invert and Brick Roof Arch.

lutely free from joints and had an invert as smooth as vitrified pipe, with a flow line which was much straighter. Tests with a level at several points showed no variation from true grade as much as 0.01 ft. It is worth repeating also that the cost of the concrete sewers built in this manner has been one-third less than the cost of brick sewers of the same dimensions. A variation of the concrete construction, which was used, is shown by Fig. 17; it consisted of a concrete invert carrying a roof arch of brick work and is shown clearly by the illustration which also shows the invert form and the arch under construction. In this view the subway is to the right, the upright I-beams which are seen being the I-beam wall columns of the standard subway construction.

In concluding this section relating to the general types and methods of construction mention should be made of the manner in which the sewers running parallel to the subway walls are carried past the occasional manhole chambers projecting from the sides of the subway. As shown by Fig. 5, previously printed there are built into the side walls of the subway a series of vitrified clay electric wire ducts. At intervals a manhole from the inside of the subway gives access to a chamber in which the ducts terminate. Fig. 18 is a sectional plan of one of these chambers, showing the manhole entrance and the manner in which the straight line of the sewer is bulged out to pass the protuberance in the normal outside wall surface of the subway.

The next succeeding article will continue the work of sewer diversion with a description of several of the large special structures which were built at important crossings.

SOME FACTORS AFFECTING THE POWER OF LOCOMOTIVES.*

By W. F. M. Goss, M. Am. Soc. M. E.

The locomotive is a complex machine. It embodies within its own structure a boiler, a pair of engines, and means for transmitting the energy of the engines to a point where it may be utilized. These several features, which are embraced by the design of every steam-power plant, are in a locomotive developed within narrow limits of space, and in a manner which adapts them to severe and exacting service. It is a high tribute to the skill of locomotive designers that in spite of limitations imposed by gage of track, by the width and height of clearance space, and by restrictions as to weight, the American locomotive has steadily increased in power until it has become the most marvelous machine that the world has ever seen. Its ability to keep in motion a slowly moving load of several thousand tons, or to run freely at the head of a lighter and more rapid train, results from the consumption of enormous quantities of coal and water. A hundred pounds of coal and two standard barrels of water are often required each minute that the locomotive is in action. If the exhaust steam delivered from its stack were in the form of solid masses of water, these would often emerge, a gallon at a time, at intervals of less than a second.

POWER, SPEED AND MEAN EFFECTIVE PRESSURE.

The energy of the boiler, after being transmitted to the cylinders, first manifests itself in pressure exerted upon the engine pistons, and in the motion of the pistons which results from this pressure. A nearer view of this process will not be without interest. The New York Central Atlantic type engine, of recent design, which for purposes of illustration may be accepted as a typical modern passenger engine, has cylinders 21 × 26 ins. Its pistons have an area of 346 sq. ins. With steam in the cylinder at 150 lbs. pressure, the force transmitted by one of its pistons is 51,900 lbs., or in round numbers 26 tons. A single stroke of one of its pistons, covering a movement of 2.16 ft. under the influence of a constant pressure of 150 lbs., represents 112,104 ft. lbs. of work; and a revolution of the engine, with its four separate strokes, gives 448,416, or practically a half million, foot-pounds. It should be observed that work thus measured is entirely independent of time and speed. The half-million foot-pounds of energy developed, in the preceding illustration, is a measure of that which must result in every revolution of the engine in question, whenever the mean effective pressure upon the pistons is 150 lbs. If we wish to measure the rate at which power is delivered, account must be taken of time. Thus, if the engine under consideration requires one minute in which to make one revolution, power will be developed at the rate of 448,416 lbs. per min. If it requires only 1 second for a revolution, power will be developed at the rate of 60 × 448,416 = 26,904,960 ft. lbs.

*A paper read before the New England Railroad Club, Dec. 3, 1901.

†Professor of Experimental Engineering, Purdue University.

per min. Now the development of 33,000 ft. lbs. of energy in 1 min. is, by general acceptance, 1 HP. Consequently, when the locomotive in question makes one revolution a minute, under the conditions stated it develops $\frac{484,416}{33,000} = 13.6$ HP., and when it makes one revolution in a second, it develops $\frac{26,904,960}{33,000} = 816$ HP.

In these illustrations a constant effective pressure of 150 lbs. per sq. in. has been assumed to act upon the engine pistons for all conditons of speed. It is evident that, under conditions thus defined, each increment of speed brings an equal increment of power, or, stating the fact in more general terms, the power developed is proportional to the speed. But it is important to note that under conditions of service, and especially under the influence of changes in speed, a constant mean effective pressure is difficult to maintain, and as a result the power of a locomotive in service is not ordinarily doubled when the speed is doubled, or halved when the speed is reduced one-half. The reasons for this will appear later.

Referring again to the examples given, it will be evident that, if the effective pressure had been assumed to be one-half of 150 lbs., the power developed in each case would have been halved, or, if it had been assumed to be one-fourth of 150 lbs. the power developed in each case would have been one-fourth of that which was obtained; from which it appears that, with a given engine at a constant speed, power is proportional to the mean effective pressure.

The significance of the fact just stated leads to an inquiry as to conditions affecting the value of the mean effective pressure; for it is evident that if, for a given engine, this can be greatly increased, the power will be increased by a corresponding amount. The discussion of this question most conveniently involves a consideration of data obtained from the Purdue experimental locomotive Schenectady No. 1.* Thus, Fig. 1 presents values for mean effective pressures, as disclosed by a series of 12 tests run at different speeds and cut-offs. Comparisons along horizontal lines show the effect of increasing the cut-off at constant speed, as, for example, at 15, 25, 35, 45, and finally at 55 miles, respectively. Again, comparisons along vertical lines show the effect of changes in speed when the cut-off remains constant. Thus, with a cut-off of 6 ins., there are given the mean effective pressures for speeds varying from 15 mi. to 55 mi., as are similar values for a cut-off of 8 ins. For a 10-in. cut-off, speeds of 25 mi. and 35 mi. only are shown; it being impracticable to extend points at this cut-off for speeds much below 25 mi. or much above 35 mi., since, for speeds lower than 25 mi., the energy developed in the cylinders becomes so great that, under the conditions of the testing plant, the drivers slip, and an attempt to run tests above 35 mi. failed because the boiler could not supply steam.

We may now see why it is that the power of a locomotive is not proportional to its speed when the cut-off remains unchanged. Thus, referring to Fig. 1, and comparing tests for which the cut-off remains constant, it will be seen that each increment of speed results in material loss in mean effective pressure. This is a result of wire-drawing. All forms of valve gear usual in locomotives give a straight steam-line only when the speed is very low. As the speed is increased, the steam-line falls, the amount of steam taken into the cylinder each revolution is diminished, and the exhaust becomes less complete. It is but proper to add that an exhibit such as appears in Fig. 1, presenting results obtained from a more modern engine with greater valve travel, or with an Allen-ported valve, or with a well-designed piston valve, might show the mean effective pressure to be somewhat better sustained under the influence of increasing speed than the results which are here given. But all differences in the performance of different engines are in this respect only matters of degree.

*This engine is of the American type, eight wheeled, with principal dimensions as follows:

Total weight, lbs.	85,000
Weight on drivers, lbs.	56,000
Drivers, diameter outside of tire, ins.	63
Cylinders, diameter, ins.	17
Stroke, inches	24
Boiler, diameter, ins.	52
Grate area, sq. ft.	17.5
Heating surface, sq. ft.	1,214

STEAMING CAPACITY.

The maintenance of pressure in the cylinders demands steam from the boiler, and hence the limit of cylinder work is reached when the boiler can no longer meet the demand which is made upon it. The pounds of steam generated per hour by the Purdue locomotive is represented by Fig. 2. The extent of the demand which the cylinders make upon the boiler under different conditions of speed and cut-off is here clearly shown. The points represented by the shaded rectangles are those for which the hourly evaporation is more than 12,000 lbs. of water, and represent a close approach to the maximum power of the boiler when fired with Indiana block coal. But with better fuel it is probable that a total of 18,000 lbs. of water per hour can be reached, which is equal to the evaporation of 15 lbs. per sq. ft. of heating surface per hour. Accepting this latter value as representing the maximum capacity of the boiler of the Purdue locomotive, then the points of cut-off and speed, for which this boiler will serve to meet the demands of the cylinders under a fully-open throttle, will be represented by the curve in Fig. 2. Thus, at 25 mi., steam can be supplied for a cut-off of almost 12 ins.; while, at a speed of 50 mi., the cut-off cannot be longer than 10¼ ins.. An attempt to employ longer cut-offs will result in failure through lack of steam. This curve represents maximum performance, under a wide-open throttle, for the engine in question. It shows also the effect of changes in speed upon the total consumption. Thus, comparing tests for which the cut-off is the same, it will be seen that the demand upon the boiler is not greatly increased by increasing the speed. The reason for this has already been explained; but it will be of interest to note that the upper portion of the curve of maximum performance is so nearly vertical that, after the speed has reached 25 mi., but slight reduc-

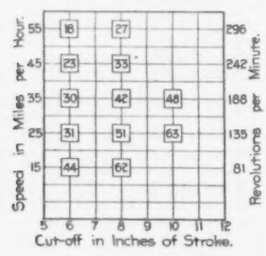


Fig. 1. Mean Effective Pressure at Different Speeds and Cut-Offs.

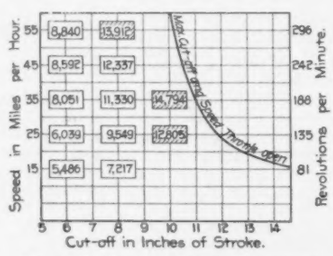


Fig. 2. Total Dry Steam Consumed, in lbs. per hr., at Different Speeds and Cut-Offs.

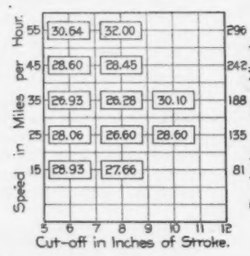


Fig. 3. Steam Consumption per HP. per hr., in lbs., at Different Speeds and Cut-Offs.

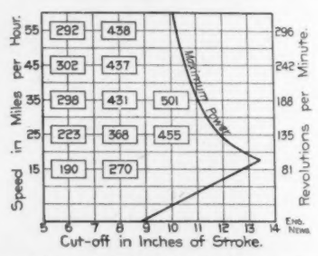


Fig. 4. Total Indicated Horse-power, at Different Speeds and Cut-Offs.

FIGS. 1-4. PERFORMANCE DIAGRAMS OF PURDUE EXPERIMENTAL LOCOMOTIVE, SCHENECTADY NO. 1.
Boiler Pressure, 130 lbs. per sq. in. Throttle Fully Open.

tions in the cut-off are required to enable the boiler to meet the demand of the cylinders under further increments of speed. Doubling the speed from 25 mi. to 50 mi. necessitates a reduction in the cut-off of less than 2 ins., whereas, if it were not for the wire-drawing action, it might be expected that doubling the speed would necessitate the use of half the cut-off.

With a constant weight of steam available, which for the Purdue engine is assumed to be maximum at 18,000 lbs. an hour, it is evident that, at the limit, the total power developed will depend upon the efficiency of the engine. Thus, at the limit of boiler capacity, when all steam generated is being consumed, the maximum power of cylinders which require 40 lbs. of steam per HP. per hour can only be half as great as that for cylinders requiring but 20 lbs. of steam per HP. per hour. It is for this reason that, at the limit, economy in the use of steam becomes a factor in determining the maximum output of power.

STEAM CONSUMPTION AND POWER.

The steam consumption of the Purdue locomotive at different speeds and cut-offs, with 130 lbs. boiler pressure and a fully-open throttle, is shown by Fig. 3. As in the diagrams previously presented, the field covered by these results represents the whole range to which, in service, the locomotive is likely to be subjected. The variation in economic performance throughout this wide range of action is extremely small. Moreover, the values presented show the locomotive to compare favorably in its performance with that of other types of high-pressure engines.

The power developed by the Purdue engine under different conditions of speed and cut-off, and under a fully-open throttle, is shown by Fig. 4. Under the conditions of maximum steam supply, as defined by the previous diagram, the greatest power which can be obtained, without exhausting the boiler of steam, is approximately 500 HP.; and the cut-off and speed necessary to give this power is shown by the curved line, Fig. 4. The lower straight line represents cut-off and speed as limited by the adhesion of the drivers, which are assumed to slip when the tractive force reaches 12,000 lbs. The entire range of action o this engine under a full throttle is represented by th area of that portion of the diagram which is to the lef of these curves.

All of these results are from an engine which is considered small in comparison with modern construction and carrying a low steam pressure, but which is neverthe less in many essential respects typical of present practice. The data exhibited disclose certain fundamental conditions applying to all locomotives which are always true. To these we may now give attention.

STEAM DISTRIBUTION.

In an appreciation of the importance of increasing mean effective pressure, resort is often had to devices which appear to give some advantage in increasing the power of the engine, but which are in fact fallacious. Thus, a change in the proportions or setting of slide valves may result in a larger mean effective pressure for a given position of the reverse lever, and the argument is advanced that the power has been increased. Or modifications in valve gear may be made which, in popular phrase, are designed to "fill out the card," that is, to straighten the steam-line, to square the corners, and to give withal an increased mean effective pressure. Any such change which may result in an enlarged card for a given position of the reverse lever, is invariably brought forward as evidence of an increase of power. But such evidence is not conclusive. A detail which accomplishes no more than an increase in the mean effective pressure for a given position of the reverse lever, accomplishes nothing which might not have been more easily attained by its omission and by merely advancing the reverse lever on its quadrant. Under all conditions for which the speed of the engine is sufficient to permit the adhesion of the drivers to absorb the full power of the cylinders, the maximum power depends upon the boiler capacity and upon the efficiency of the engines, and upon nothing else. Whatever may contribute to enlarging the steaming capacity of the boiler contributes to an increase of power, and whatever operates to reduce the consumption of steam

tests run at different speeds and cut-offs. Comparisons along horizontal lines show the effect of increasing the cut-off at constant speed, as, for example, at 15, 25, 35, 45, and finally at 55 miles, respectively. Again, comparisons along vertical lines show the effect of changes in speed when the cut-off remains constant. Thus, with a cut-off of 6 ins., there are given the mean effective pressures for speeds varying from 15 mi. to 55 mi., as are similar values for a cut-off of 8 ins. For a 10-in. cut-off, speeds of 25 mi. and 35 mi. only are shown; it being impracticable to extend points at this cut-off for speeds much below 25 mi. or much above 35 mi., since, for speeds lower than 25 mi., the energy developed in the cylinders becomes so great that, under the conditions of the testing plant, the drivers slip, and an attempt to run tests above 35 mi. failed because the boiler could not supply steam.

We may now see why it is that the power of a locomotive is not proportional to its speed when the cut-off remains unchanged. Thus, referring to Fig. 1, and comparing tests for which the cut-off remains constant, it will be seen that each increment of speed results in material loss in mean effective pressure. This is a result of wire-drawing. All forms of valve gear usual in locomotives give a straight steam-line only when the speed is very low. As the speed is increased, the steam-line falls, the amount of steam taken into the cylinder each revolution is diminished, and the exhaust becomes less complete. It is but proper to add that an exhibit such as appears in Fig. 1, presenting results obtained from a more modern engine with greater valve travel, or with an Allen-ported valve, or with a well-designed piston valve, might show

FUNDAMENTAL RELATIONS.

The results already described, as obtained experimentally from the Purdue locomotive, will, if properly interpreted, serve as a means whereby the performance of any

locomotive may be predicted. A review of the various factors which should be given consideration in such a process is appended to this paper. A summary of the more important conclusions is to the effect that any ordinary locomotive boiler may be depended upon to evaporate each hour 12 lbs. of water for each sq. ft. of heating surface; that when working at full power, under the varying conditions of speed and cut-off at which that power may be developed, it requires approximately 27 lbs. of steam per indicated HP. per hour; and, consequently, that 1 HP. may be developed in the cylinders for each 2¼ sq. ft. of heating surface in the boiler. By this process it becomes possible to determine the power of any locomotive from the known area of its heating surface. Power thus determined should be equivalent to the indicated power; but, since the indicator does not enter into the measurement, it will hereafter be referred to as the cylinder horse-power, or as the C. H. P. If the square feet of heating surface is represented by H, the general equation for the power of a locomotive becomes,

C. H. P. = .43 H.

This equation is assumed to apply to simple engines only. It does not apply with strict accuracy to any particular engine, or to any specific condition of running. It is merely an approximate measure of the maximum power which will be developed by a fairly representative modern engine under ordinary conditions of service. Its use is justifiable because of certain interesting and useful comparisons it permits. Its application to the New York Central's Atlantic type passenger engine gives a little over 1,500 HP. as the capacity of that engine.

For any engine, the draw-bar stress as developed in the appendix is obtained by the equation,

$$\text{Pounds draw-bar stress} = 375 \times \frac{\text{C. H. P.}}{\text{speed in mi. per hr.}}$$

When applied to the New York Central's Atlantic type passenger engine at a speed of 10 mi. per hr., this equation gives a draw-bar stress of 56,250 lbs., and at 50 mi. per hr., of 11,250 lbs., while results for all speeds are represented by the curve in Fig. 5. This diagram, applying only to the New York Central engine, represents the maximum tractive effort of this engine in ordinary service, assuming that all the energy of the cylinders appears as a stress on the draw-bar. So far as the mathematical relations involved are concerned, the curve may be extended in either direction indefinitely, but practical considerations establish limits. The limit of its extent upwards is found when the tractive force equals the adhesion of the locomotive, and the limit of its extent to the right is reached when the speed of revolution reaches a fixed maximum. The maximum adhesion is usually assumed to equal one-fourth the weight on drivers, which, for the New York Central engine with its 95,000 lbs. on drivers, is 23,750 lbs. By use of its traction-increaser and of sand, this value may be greatly exceeded, but the normal limit as shown will serve the present purpose. The maximum speed is somewhat more difficult to fix. It has been stated, as a rule of practice followed by a locomotive-builder, that the diameter of the drivers in inches is made to equal the maximum speed of the locomotive in miles per hour. Upon this basis, which allows all engines a maximum speed of rotation of 336 revolutions a minute, the limit of speed of the New York Central engine, with its 79-in. drivers, is 79 mi. per hr., and the diagram should be cut off at this point, that is, along the line C D. Within limits thus defined, the curve is a perfect definition of the theoretical maximum pulling-power of the engine under consideration. It shows that the engine may be started from rest at its maximum tractive force of 23,750 lbs., and may continue to exert this force until a speed of 24 mi. per hr. is reached. At this point (point B) the power, which at lower speeds has been less than that which the cylinders are capable of exerting, becomes maximum at 1,500 HP. Beyond this point, each increment of speed is attended by a loss in tractive force, until at the maximum speed of 79 mi. it becomes reduced to 7,000 lbs.

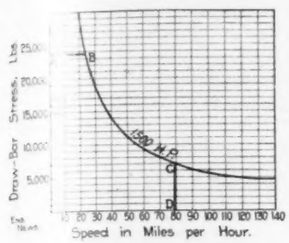


Fig. 5. Tractive Force Equivalent to 1,500 Cylinder HP., Assuming no Loss Between Cylinder and Driver.

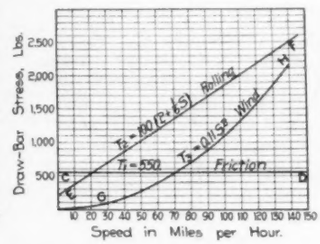


Fig. 6. Losses of Tractive Force Between Cylinder and Drawbar.

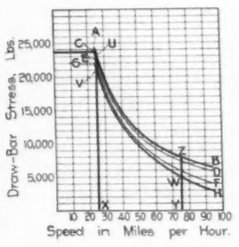


Fig. 7. Tractive Force Corrected for Losses.

FIGS. 5-7. DIAGRAMS OF DRAWBAR STRESS, NEW YORK CENTRAL ATLANTIC TYPE PASSENGER LOCOMOTIVE.

2. Rolling resistance of trucks and tender;

3. Resistance which the atmosphere offers to the head of the train.

There may be other resistances, as, for example, the flange friction due to side winds, but these are exceptional and are constantly varying in value. For this reason they will be omitted in a consideration of the general case, with which we may now proceed.

1. The machine friction of a locomotive has been investigated through the medium of rather elaborate experiments made upon the testing plant of Purdue University. The process involved simultaneous observations at the cylinders and at the draw-bar, while the engine was running at a constant speed and under a constant load. Indicators on the cylinders served in giving a measure of the power developed at that point, and an accurate dynamometer was employed to give the pull at the draw-bar. If there had been no frictional loss, these two sets of results, when reduced to the same basis, would have been identical. But they were in fact different, and the extent of the difference represents loss in transmission. These experiments were made with very great care. That the engine might be perfectly free to respond to forces transmitted from the drivers, the engine truck was removed, and the front of the engine was suspended from long rods so located that the least force tending to displace the machine would produce an effect upon the dynamometer, to which the draw-bar was connected. The whole work was many times repeated at many different speeds and loads. From results thus obtained it appeared that, for the Purdue locomotive Schenectady No. 1, the frictional resistance was represented by a mean effective pressure of 3.8 lbs., and that this value remained nearly constant for all speeds and cut-offs. Whether the higher pressures of the more modern engine operate to increase this value cannot definitely be determined, but, judging from the Purdue results, the increase, if any, would be slight. In the absence of more definite information, we can do no better than accept the fact stated as of general application. While it is not likely that such a course can lead to a highly refined degree of accuracy, it is certain that it is not far from the truth. Assuming, then, that the New York Central engine requires a mean effective pressure of 3.8 lbs. to overcome its machine friction, the equivalent draw-bar stress, as determined from the known dimensions of the engine, is 550 lbs. That is, this is the force which must be exerted at the draw-bar to keep in motion the pistons, cross-heads, valves, rods and all connected machine parts, including the axles and flanges of coupled wheels. The significance of this statement is shown by the line C D, Fig. 6.

2. The resistance to rolling, offered by trucks and tender, cannot be much different from that of an equal weight of train following the tender, a fair estimate of which is represented by the formula, $T_2 = 2 + 1/6\ S$, in which T_2 is the resistance of each ton weight, and S is the velocity in miles per hour. The rolling load of the New York Central engine, exclusive of that carried by drivers, the resistance of which has been included with the machine friction, is as follows:

Weight on truck	42,000 lbs.
Weight on trailing wheel	48,000 "
Weight on tender in working order	110,000 "
Total	201,200 "

The formula shows that the tractive force necessary to overcome this rolling load of practically 100 tons, at a speed of 10 mi. per hr., is 366 lbs., and, for a speed of 50 mi. per hr., 1,033 lbs., values for all speeds being shown by the line E F, Fig. 6.

3. The resistance offered by the atmosphere to the head of a train was investigated some years ago by means of a model train mounted within a conduit, through which currents of air, of any velocity up to that of 100 mi. per hr., could be made to pass. Each element of the train was mounted upon a dynamometer in such a manner as to indicate the value of any force tending to displace it longitudinally. It was assumed that the effects observed by having the train at rest, and the air moving past it, would be the same as would have been observed had the air been still and the train in motion through it. The results showed that the resistance offered by still air to the progress of the locomotive and tender at the head of a train is approximately ten times greater than that which acts upon an intermediate car of the same train, the formula being $T_3 = .11\ S^2$, where T_3 is the tractive force in pounds necessary to overcome the resistance offered by still air to the progress of a locomotive at the head of a train, and S the velocity of the train in miles per hour. The formula makes the resistance which the atmosphere offers to the motion of a locomotive, at a speed of 10 mi. per hr., 11 lbs., and, at a speed of 50 mi., 275 lbs., and for all speeds as shown by the curve G H, Fig. 6.

NET DRAW-BAR STRESS.

We have now obtained a measure of the draw-bar stress equivalent to the power developed in the engine cylinders, assuming no loss in transmission, which for the New York Central engine is shown by Fig. 5, and of the several losses which in service occur between the cylinder and the draw-bar. If now we apply these latter measures as corrections to the former, the results should be a measure of the forces actually developed at the draw-bar. The effect of this process as applied to the New York Central locomotive is most easily made apparent by a graphical process in which the curves of Fig. 7 are combined with that of Fig. 5. The result is shown by Fig. 7. In this figure the curve A B is the same as that given in Fig. 5. It is the draw-bar pull as calculated from cylinder work, disregarding engine friction and all other incidental losses. Applying to this curve the correction for machine friction which is defined by the curve C D, Fig. 6, we shall need to measure down on each ordinate a distance from the curve A B of 550 lbs. The result is the line C D, Fig. 7. Similarly, to make a further correction for the resistance of the rolling load, values from the curve E F, Fig. 6, are laid off downward from the curve C D, resulting in the line E F, Fig. 7. And finally, to correct for wind resistance, values from the curve G H, Fig. 6, are laid off downward from the curve E F, resulting in the curve G H, Fig. 7. In the completed

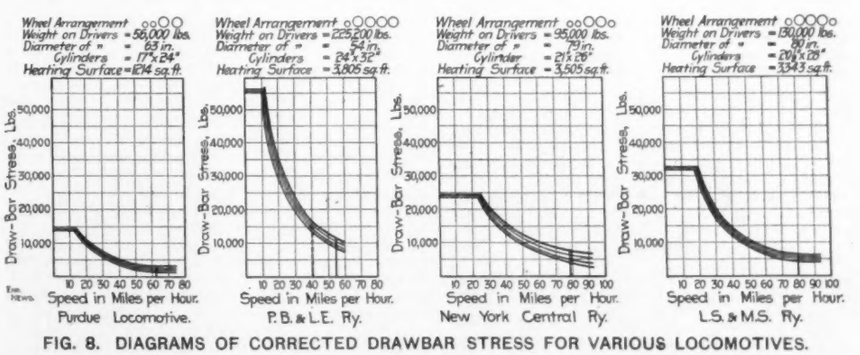

Wheel Arrangement
Weight on Drivers = 56,000 lbs.
Diameter of " = 63 in.
Cylinders = 17"x24"
Heating Surface = 1614 sq.ft.
Draw-Bar Stress, Lbs.
Speed in Miles per Hour.
Purdue Locomotive.
Weight on Drivers = 225,200 lbs.
Diameter of " = 54 in.
Cylinders = 24"x 32"
Heating Surface = 3,805 sq.ft.
P.B.&L.E. Ry.
Weight on Drivers = 95,000 lbs.
Diameter of " = 79 in.
Cylinder = 21"x 28"
Heating Surface = 3,505 sq.ft.
New York Central Ry.
Weight on Drivers = 130,000 lbs.
Diameter of " = 61 in.
Cylinders = 20½"x 28"
Heating Surface = 3343 sq.ft.
L.S.&M.S. Ry.

FIG. 8. DIAGRAMS OF CORRECTED DRAWBAR STRESS FOR VARIOUS LOCOMOTIVES.

diagram (Fig. 7), the area between the first curve A B and the second C D, represents frictional losses; that between the second C D and third E F, represents rolling resistance of trucks and tenders; that between the third E F and the fourth G H, represents atmospheric resistance; and that between the fourth G H and the horizontal axis, the forces which are available at the tender coupler for useful work in drawing a train. It will be seen that, at a speed of 25 mi. per hr., the stress at the draw-bar is 21,500 lbs., while, when the speed is increased to 75 mi. per hr., the draw-bar stress is reduced to 5,000 lbs.

Some insight into the cost of running trains at high speeds may be had by comparing the percentage of the cylinder effort, which is lost when the speed is low, with that which is lost when the speed is high. Thus, at a speed of 25 mi. per hr., the line U V is only 7.5% of the line U X, while, at a speed of 75 mi. per hr., the line Z W is 40% of the line Z Y. The relation of lost work to total work developed in the two cases is proportional to the length of the lines referred to.

The values shown by Figs. 6 and 7 are applicable to the New York Central Atlantic type passenger engine only, but similar relationships may readily be developed which will be of general application. The general case can best be developed by means of the equations of the several curves involved. These appear in the appendix to this paper. The result of their application to four well-known engines is shown by Fig. 8.

A study of the diagrams of Fig. 8 will disclose some of the advantages which attend the use of heavy and powerful engines. Thus, comparing the performance of the Purdue locomotive, a representative engine of ten years ago, with that of the modern New York Central Atlantic type, it appears that, at a speed of 60 mi. per hr., the actual draw-bar stress of the former is reduced to below 2,000 lbs., while that of the latter is not less than 7,000 lbs. At 70 mi. per hr. the pull of the Purdue engine drops to 1,000 lbs., whereas that of the New York Central engine is five times this amount. These are results due to the greater power available, and to the fact that the losses betwen cylinder and draw-bar are relatively less for heavier engines than for lighter engines.

Some of the effects of different diameters of drivers are to be seen by a comparison of the diagrams of the Pittsburg, Bessemer & Lake Erie engine and the Lake Shore & Michigan Southern engine. The former, with its 54-in. drivers and its enormous adhesive weight, gives at slow speed a draw-bar pull of not less than 55,000 lbs., which is more than 50% in excess of the maximum pull of the Lake Shore engine. The small-wheeled engine is able to develop the full power of its cylinders when a speed of 10 mi. per hr. is reached, whereas this result is not secured by the large-wheeled engine until a speed of 18 mi. per hr. is attained. Correcting for losses between the cylinder and draw-bar, it appears that, for a speed of 40 mi. per hr., the tractive effort of the two engines becomes equal. Again, assuming the maximum speed in miles per hour to equal the diameter of the drivers in inches, the Pittsburg, Bessemer & Lake Erie engine reaches its limit at 54 mi., whereas the Lake Shore engine continues to run until 80 mi. are reached. Actual difference in respect to maximum speed would be greater than that which is shown; for, while the Lake Shore engine with its large wheels and proportionately lighter reciprocating parts may readily attain a speed approaching 400 r. p. m., such a speed would be impossible with the smaller wheels and proportionally heavier reciprocating parts of the Pittsburg, Bessemer & Lake Erie engine. The basis of comparison in this respect is, therefore, more favorable to the small-wheeled engine than it should be. If the maximum speed limit of the small-wheeled engine be fixed at 40 mi. per hr., its entire range of action is represented by the area of the diagram to the left of the dotted line, which area is to be compared with the full area of the diagram of the large-wheeled engine. It will be seen that increasing the diameter of the drivers, greatly increases the possible range of action, and, further, as it tends to diminish frictional losses, it serves in sustaining the draw-bar pull as the speed is increased.

APPENDIX: GENERAL FORMULAS.

EVAPORATIVE POWER.—The records obtained from the Purdue locomotive disclose several tests for which the evaporation is above 12 lbs. of water per sq. ft. of heating surface per hour, and the maximum record for the engine is 14.6 lbs. These results were obtained with Brazil block coal, which is of a light and rather friable character. While they were secured at the expense of very hard firing, it is probable that, with a superior grade of fuel, higher rates of evaporation could have been had, and that a possible maximum for this boiler need not be lower than 15 lbs. In accepting this limit, it should be considered a possible maximum merely. It is at least three pounds higher than the practical maximum which can be relied upon in service for continuous work, using Brazil coal. For short intervals of time, the output of a locomotive boiler may be greatly increased beyond the normal maximum, but this is done at the sacrifice of fire condition or of water level. Power obtained by such means is the result of abnormal development, and is not a subject for consideration in connection with the present discussion.

From these considerations it is proposed to accept 12 lbs. of water per sq. ft. of heating surface per hour as a fair measure of high performance for the Purdue engine under the ordinary conditions of the road, and as a close approach to the maximum evaporative power of all locomotives. With this understanding, the value 12 lbs. of water per sq. ft. of heating surface will be used as a measure by use of which the power of any locomotive may be predicted. It is certainly one which can be accepted for all boilers of similar design. Probably, also, it will apply to all ordinary boilers in locomotive service, though this is not settled beyond doubt. It has been suggested that boilers having large grates may be easily forced to higher limits than those given, while boilers having a large extent of heating surface and small grates may have difficulty in working up to the limit of 12 lbs. This argument is not without force, though probably it has less significance than would at first appear. Grate areas have an important influence on the efficiency of a boiler, but it is not clear that they can operate greatly to increase the power. If in each of two boilers, one having a wide grate and the other a narrow grate, the same amount of heat is liberated, the heat in passing the tubes should in each case produce the same evaporation. On the other hand, the advantage of the large grate as a power-producer appears in its ability to withstand forcing; and it must be admitted that an effort to secure maximum power in a locomotive is likely to resolve itself into a fuel-burning contest. In such a contest the larger grate is likely to have some advantage; but, for reasons stated, differences on this account will not be great.

The advantage of the relatively large boiler, which constitutes a part of the modern locomotive, lies in its ability to do the work expected of it without being forced. That is, to further the ends of economy in operation, boilers for a given service are now made larger than used to be the custom, from which it follows that, under the conditions of service, small boilers are likely to be worked under conditions which approach more nearly their maximum power than large boilers. But this, it will be observed, applies to the ordinary conditions of service. When maximum power is demanded, all boilers of whatever size are likely to be worked hard as conditions will allow.

Finally, it should be said that the measure proposed can not be a precise one. It is based on actual evaporation, which is necessarily influenced by change in steam pressure and in temperature of feed; but it is evident that the requirements of the present process are not such as make it necessary to take these into account.

From these considerations it will appear that the measure proposed is not likely to pass unchallenged; but, as one studies the problem, he will gain confidence in its value. For the present purpose, therefore, as already stated, it will be assumed that the performance of all boilers may be predicted from the known extent of their heating surface; that the measure proposed is not a measure of maximum performance, but is a close approximation thereto; and that the measure is a fairly representative maximum for ordinary conditions of service. The measure is to the effect that the pounds of water evaporated by any ordinary locomotive boiler is equal to 12 times the sq. ft. of heating surface in the boiler. Expressed in the form of an equation it is,—

Lbs. water evaporated per hr. = 12 x sq. ft. of heating surface in boiler, or E = 12 H.

STEAM CONSUMPTION.—Having now a measure of the weight of steam which a locomotive boiler may be depended on to deliver, we may next make inquiry concerning the degree of economy attending the consumption of steam by the cylinders. The steam consumption per horse-power per hour for the Purdue engine, for all speeds and cut-offs within its range of action, under a full throttle, has already been presented in Fig. 4. Assuming that this engine was designed to work at speeds varying from 25 to 55 mi. per hr., and at loads necessitating a cut-off from 6 to 10 ins., there are required, as shown by the diagram (Fig. 4), from 26.28 to 32.00 lbs. of steam per HP. per hr. The maximum limit of 32 lbs. is exceptional. A single value which fairly represents the actual performance of this 17 x 24 engine, working under 130 lbs. steam pressure, is 28 lbs. The modern engine, having large cylinders and profiting by higher steam pressures, can undoubtedly reduce this consumption to a point which will make 27 lbs. a representative figure, and this value will for the present be accepted as representing the normal performance of a modern engine under its usual range of action. It is not the minimum value, for this is from 2 to 2½ lbs. lower; nor is it the maximum, for the maximum may greatly exceed the measure stated. But it is, as has been stated, a value which represents the average consumption under a considerable range of action.

We are now prepared to express cylinder power in terms of heating surface. Thus, if 28 lbs. of steam are required each hour for the development of a horse-power; and if each foot of heating surface yields 12 lbs. of steam per hour, then:

$$\text{Cylinder HP.} = \frac{\text{Total lbs. of water evaporated per hr.}}{\text{Lbs. consumed per HP. per hr.}} = \frac{12\,H}{28},$$

Or,

$$\text{C. H. P.} = 0.43\ H.$$

As this equation is one of great significance, it should be noted that the process leading up to its development has presented several steps, some of which have been subject to qualification. It is evident that the accuracy of the concluding statement cannot be greater than that of the parts of which it is composed. The claim is that the equations as given may be accepted as representing a fair estimate of the maximum power which is continuously sustained by modern engines engaged in ordinary service.

DRAW-BAR PULL.—Assuming no loss between cylinder and draw-bar, then for any locomotive,

Work developed in the cylinders = the work given out at the draw-bar.

Therefore,

Cylinder horse-power × 33,000 × 60 = pounds stress in draw-bar × distance passed over in feet in one hour. = Stress in draw-bar × speed of train in miles per hour × 5,280.

Transposing,

$$\text{Pounds draw-bar stress} = \frac{\text{HP.} \times 33{,}000 \times 60}{\text{Speed of train in mi. per hr.} \times 5{,}280} = \frac{375 \times \text{HP.}}{\text{Speed in mi. per hr.}}$$

or,

$$T = \frac{375 \times \text{C. H. P.}}{S}$$

and substituting the value of C. H. P. found above we get

$$T = 161\ \frac{H}{S}.$$

SUMMARY OF FORMULAS.—The symbols employed in the paper and in the formulas below are as follows:

I. H. P. = Indicated horse-power.
C. H. P. = Cylinder horse-power, equivalent to I. H. P., but not necessarily obtained by means of an indicator.
H = Heating surface in boiler; in square feet.
S = Speed of engine; in miles per hour.
W = Weight of rolling load, including that on trucks and tender, but excluding that on drivers; in tons.
W_1 = Weight on drivers; in tons.
d = Diameter of piston; in inches.
L = Length of stroke; in feet.
D = Diameter of drivers; in feet.
T = Tractive force equivalent to the power developed in the cylinders, assuming no loss in transmission between cylinders and draw-bar; in pounds.
T_1 = Tractive force equivalent to machine friction, including rolling friction of drivers; in pounds.
T_2 = Tractive force equivalent to the resistance of the rolling load, including that of trucks and tender, but excluding that of drivers and machinery; in pounds.
T_3 = Tractive force equivalent to the resistance offered by still air to the movement of an engine at head of train; in pounds.
t_1 = Tractive force equivalent to cylinder power corrected for machine friction; in pounds.
t_2 = Tractive force equivalent to cylinder power corrected for machine friction and resistance of rolling load; in pounds.
t_3 = Tractive force equivalent to cylinder power corrected for all losses between cylinders and draw-bar, including machine friction, resistance of rolling load, and atmospheric resistance; in pounds.

N. B.—t_3 must never be greater than ¼ W_1 in pounds.

The formulas which have been introduced in the present discussion, or whose form has been suggested here, and which are applicable to any locomotive, are summarized below. The quantity t_3, or net draw-bar pull, is in general the one it is desired to know, for any particular speed. To determine it, the following must be known: Area of heating surface, diameter and stroke of piston, diameter of drivers, weight of rolling load and weight on drivers. Note again that no value of t_3 is to be considered practicable if greater than one-fourth the weight on drivers.

Power developed:

$$\text{I. H. P.} = \text{C. H. P.} = 0.43\ H \qquad (1)$$

Gross Draw-bar Stress:—

$$T = 375\ \frac{\text{C. H. P.}}{S} \qquad (2)$$

$$= 161\ \frac{H}{S} \qquad (3)$$

Engine and Train Losses:

$$T_1 = 3.8\ \frac{d^2\,L}{D}\ *$$

$$T_2 = W\left(2 + \frac{S}{6}\right)\ \dagger$$

$$T_3 = 0.11\ S^2\ \dagger$$

Net Draw-bar Stress:

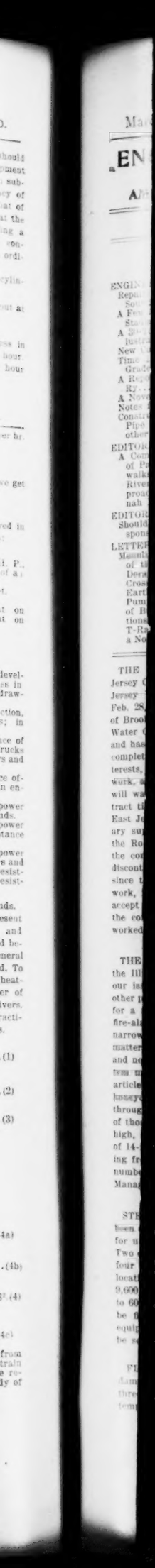
$$t_1 = T - T_1 = 161\ \frac{H}{S} - 3.8\ \frac{d^2\,L}{D} \qquad (4a)$$

$$t_2 = t_1 - T_2 = 161\ \frac{H}{S} - 3.8\ \frac{d^2\,L}{D} - W\left(2 + \frac{S}{6}\right) \qquad (4b)$$

$$t_3 = t_2 - T_3 = 161\ \frac{H}{S} - 3.8\ \frac{d^2\,L}{D} - W\left(2 + \frac{S}{6}\right) - 0.11\ S^2 \qquad (4)$$

Criterion:

$$t_3 = \frac{2{,}000\ W_1}{4} \qquad (4c)$$

*For two cylinders. The formula is easily derived from the relation between motion of piston and motion of train on the basis of 3.8 lbs. mean effective steam pressure required to overcome this resistance, as noted in the body of the paper.

†Suggested in paper above as results of tests.